Michael Holliday & Associates

SOME OCCUPATIONAL-HEALTH ASPECTS OF THE USE OF BERYLLIUM AND ITS COMPOUNDS IN ONTARIO

by

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NOTE

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ABSTRACT

The report provides a background overview of the occupational-health aspects of exposure to beryllium and its compounds in Ontario workplaces. The information presented was based on contacts with some 200 companies, labour unions, trade and professional associations, and government agencies by letter, telephone interview, and face-to-face meeting. The cornerstones of the project were a mail-out questionnaire survey of 172 establishments representing 156 Ontario companies (a 74-percent response was obtained) and walk-through surveys of a representative cross section of beryllium-material using establishments (12 plants were visited). In addition, scientific and technical publications dealing with aspects of occupational exposure to beryllium-containing materials were reviewed.

The physical and chemical properties of beryllium metal, beryllia, and beryllium alloys are discussed in relation to their industrial uses. Brief summaries of the health effects which may arise from exposure to these materials and of the analytical methods by which such exposure may be measured are presented. Processes which involve beryllium-containing materials in Ontario industry are described and the control measures (engineering and work practice) which may be used to reduce such exposure to such materials are discussed. The attitudes of management and labour representatives with regard to the potential hazards of using beryllium-containing materials are presented. In conclusion, regulatory control options available to the Ontario government are discussed and compared with regulatory approaches adopted by other jurisdictions.

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SYNOPSIS

There is no primary production or processing of beryllium ore in Ontario (or, indeed, in Canada), but three classes of beryllium-containing materials are used in the province: beryllium metal (in both billet and powder form), beryllia (as a sintered ceramic), and beryllium alloys (predominantly copper-beryllium) in which the beryllium content ranges from fractions of a percent to about two and a half percent. Beryllium-containing materials may be found in a wide variety of products manufactured in Ontario; from nuclear reactors and missile systems to electrical connectors and truck parts.

Although direct figures are unavailable, indirect evidence suggests that 3.5 to 6 tonnes of beryllium alloys and 220 to 270 kg of pure beryllium metal are consumed annually in Ontario. The quantities of beryllia currently used in the province, however, are very small and are probably less than 100 kg per year. It is estimated that 3600 to 4800 workers in Ontario would deal in some way with beryllium-containing material and, of these, some 900 to 1200 may potentially be exposed to airborne beryllium. The occupational exposure limit for beryllium and its compounds, a TWAEV of 2 $\mu g/m^3$ (measured as beryllium), is among the most stringent mandated for Ontario workplaces.

PROPERTIES, HEALTH EFFECTS AND ANALYSIS

The beryllium-containing materials used commercially — the metal itself, beryllia, and beryllium alloys — all have similarly good thermal conductivities. The metals (pure beryllium and beryllium alloys) possess good electrical conductivity and are comparatively resistant to corrosion. Beryllia is an excellent electrical insulator and is chemically inert.

There are a number of adverse health effects associated with exposure to beryllium and its compounds, some (and maybe most) of them mediated by a latent hypersensitivity to beryllium in some individuals:

- contact dermatitis;
- acute irritation in eyes contaminated by beryllium-containing material;
- ulceration of cuts contaminated by soluble beryllium compounds;
- chronic granulomatous skin disease; and

- acute and chronic lung diseases — forms of pneumonitis in their most severe manifestations (the chronic disease, berylliosis, exhibits latency periods of up to twenty years).

The IARC and the ACGIH both recommend that beryllium be considered suspect of being carcinogenic to humans.

Atomic absorption spectrometry is the analytical technique used to monitor occupational exposure to beryllium. This technique can be used both for air and surface samples and for the measurement of beryllium excreted in the urine of exposed individuals. Urinalysis for beryllium is not, however, considered a reliable quantitative measure of beryllium exposure. It can merely indicate that exposure might have occurred. Lymphoblast transformation is regarded as the most useful test to detect beryllium hypersensitivity in humans.

MANUFACTURING OPERATIONS INVOLVING BERYLLIUM OR ITS COMPOUNDS

Although the quantities of beryllium, beryllia, and beryllium alloys used in Ontario are not large (certainly in comparison with other non-ferrous metals and alumina), the materials are widely dispersed within Ontario industry and are used for a diversity of applications. The occupational exposure potential, through not necessarily the actual exposure, varies from high (e.g., operations involving pure beryllium in a powder form) to the non-existent (e.g., assembly of parts containing fractions of a percent of beryllium).

Beryllium Metal

Beryllium metal is used in the manufacture of certain specialized equipment for aerospace and military applications (e.g., gyroscopes used in inertial guidance systems, parts for a speciality camera). This manufacture demands high-precision machining of beryllium (often to within a few ten thousandths of an inch) using miniature lathes, drills, grinders and even sand-blasting equipment. All machining equipment is enclosed and provided with local ventilation.

Beryllium is used in the brazing of zircaloy spacers to fuel tubes which make up the fuel bundles used in Candu reactors. The process is essentially a three stage operation which takes place before the zircaloy tubes are charged with the uranium dioxide fuel and consists of: vacuum deposition of beryllium metal onto the spacers, tack welding spacers on the zircaloy fuel tubes, and radio-frequency induction brazing of the tacked spacers to the fuel tubes. Another nuclear application is the use of a beryllium neutron reflector in a small research reactor manufactured in Ontario. The shield, which surrounds the reactor core, is machined under contract by a United States supplier.

Beryllia

Beryllia is a ceramic material used as a substrate for hybrid micro-electronic circuits which require exceptional heat dissipation characteristics. (Most such circuitry, however, employs alumina as the substrate; a material with a much lower thermal conductivity than beryllia.) Three operations in microcircuit manufacture could result in the generation of airborne substrate materials (beryllia or alumina): laser scribing, laser trimming of resistors, and separation of individual microcircuits. It is uncertain whether any companies in Ontario currently manufacture microcircuits on beryllia substrates. There are companies, however, that use beryllia in some assembly work.

Beryllium Alloys

By far the most common beryllium containing materials used in Ontario are beryllium alloys — predominantly copper-beryllium. Their production, application and use embrace a variety of different Ontario industries.

Both copper-beryllium and aluminum-beryllium alloys are produced in Ontario. The alloys are used to produce a multiplicity of castings and forgings. Potential for occupational exposure to beryllium in such operations exists during the melting of the alloys, the pouring of the castings, and removal of extraneous metal from the casting.

Copper-beryllium alloys are machined to produce a number of products, of which moulds for injection- and blow-moulding of plastic products, bushings (e.g., wing-pick-up bushings in aircraft), and resistance welding electrodes are the most clearly identifiable categories. Copper-beryllium strip is used in stamping operations to form electrical connectors and contacts, and numerous kinds of fastenings. Copper-beryllium wire is formed into all sizes and grades of springs. The primary source of airborne beryllium-containing material in these activities would be machine-shop operations involving "dry" working of the alloy (particularly grinding and sanding). Forming and stamping operations are unlikely to result in airborne material.

Copper-beryllium is used in "secondary" operations (i.e., operations in which the alloy is not directly converted into other products) as a tool component. Resistance welding, probably the most widespread use in this category, is extensively employed in the manufacture of automobiles and large household appliances. The welding electrodes are in many instances made of copper-beryllium alloy. Exposure potential is slight and would mostly be confined to maintenance of the electrodes (e.g., refacing of welding wheels). Copper-beryllium plays a small but critical role in aluminum die-casting. The plunger tip in the die-casting equipment is made of copper-beryllium. The tip, which forces the molten metal into the die, becomes worn in use. Periodically, the tips have to be refurbished by machining and grinding.

Finally, there are a variety of assembly operations in which copper-beryllium components are used. Typical examples are electronic connector assemblies, electrical switchgear, spring operated assemblies, and brake assemblies for heavy duty trucks. Exposure potential is non-existent because there are no processes in the assembly of such articles which result in destruction of copper-beryllium.

BERYLLIUM EXPOSURE AND ITS CONTROL

By and large, the exposure-control measures adopted in establishments handling beryllium-containing materials reflect the companies' perceptions of the hazards of beryllium exposure within their particular manufacturing operations. These measures range from the comprehensive and stringent to the non-existent. Operations which solely involve assembly of beryllium-metal or beryllium-alloy components pose virtually no exposure hazard and hence no exposure-control measures are considered necessary by the companies involved in this activity.

Beryllium Metal Users

Although the processes used in the two activities involving beryllium metal in Ontario, namely high precision machining and brazing spacers on the fuel sheaths for Candu nuclear reactors, are different, the exposure-control approaches adopted by the companies are similar.

The handling of beryllium takes place in restricted-access areas equipped with dedicated area ventilation systems (i.e., the systems are not connected to the ventilation for other areas in the facilities). Much of the beryllium handling equipment is enclosed and provided with local exhaust ventilation. Access to the beryllium-handling areas is via changing rooms and is limited to designated employees. Coveralls, designated footwear and, where necessary, particle respirators are worn by persons in the restricted beryllium areas. Nothing is permitted to leave the controlled area without first being decontaminated; this precaution prevents "tracking" of beryllium into other areas of the plant. Laundry facilities for washing the coveralls are located within the controlled areas. Eating, smoking and drinking within controlled areas are prohibited.

There is regular monitoring of atmospheric beryllium levels in all the plants. Monitoring of surface contamination ("swipe tests") is also done on a regular basis. Results of the monitoring are periodically published in the workplaces. Exposure levels are generally below 0.5 μg Be/m^3 in areas where machining of beryllium is carried out, and below 2 μg Be/m^3 in areas where vacuum deposition of the metal is undertaken.

There appear to be six to eight workers employed daily in machining beryllium in Ontario, and a further 150 to 200 workers who have access to the machining areas on an intermittent basis. There are about 60 workers who are exposed daily to beryllium in activities connected with the brazing of spacers onto Candu fuel sheaths; some four to six of these are employed in the vacuum-deposition areas. All designated beryllium workers undergo yearly medical examinations, with particular attention being paid to lung condition.

Beryllia Users

It is uncertain whether there is any company in Ontario that currently manufactures hybrid microcircuits on beryllia substrates, but at least one company may be doing so in the future. The control of exposure to airborne beryllium during manufacture of microcircuits on beryllia substrates depends on enclosure of equipment and local exhaust ventilation, as well as on an awareness among the workforce that it is toxic beryllia which is being handled rather than the visually similar and much more common non-toxic alumina. From the few data regarding atmospheric beryllium levels generated by processes involved in producing microcircuits (breathing-zone levels ranging from non-detectable to 1.5 µg Be/m^3) it appears that equipment (e.g., laser scribers and trimmers) used for the manufacture of microcircuits on alumina may be also used for beryllia with little or no modification.

There is one company (and there may be one or two others) which produces electronic devices assembled on a beryllia base. The company employs simple work-practice controls, prime among which is the precautionary labelling of each beryllia device at every stage of the manufacturing process. The company has a very thorough and clearly identified clean-up procedure to be followed if beryllia substrates or circuits are dropped and broken: area evacuation, clean-up by a specially trained team wearing respirators and using a specially exhausted vacuum cleaner, and careful bagging of the broken pieces for disposal.

There are possibly some 15 to 30 workers in Ontario engaged in electronic assembly work involving beryllia substrates. This work, however, is not likely to be conducted on a full-time basis.

Beryllium Alloy Users

In contrast to the practices employed in operations involving beryllium metal or beryllia, there are few control measures used to specifically reduce beryllium exposure in operations involving beryllium alloys. Normal metal-handling and machine-shop practices are usually considered adequate.

In foundries, local exhaust ventilation is provided at the alloy-melting crucibles, in the area where castings are being poured, and at work stations where excess metal is removed from the casting by sawing, grinding, and routing. One company required workers to wear supplied-air respirators when carrying out welding repair of minor surface defects in beryllium-containing castings. No clear idea of beryllium exposure levels encountered in foundry operations was obtained, but representatives of the industry indicated that they thought exposure was generally below 1 μg Be/m^3. Perhaps some 150 to 200 workers are involved in casting and forging operations dealing with beryllium alloys.

Machining of copper-beryllium under "wet" conditions (i.e., with the use of adequate quantities of coolants and cutting fluids) prevents appreciable exposure to airborne beryllium. "Dry" grinding of the alloy presents the greatest potential for excessive exposure to airborne beryllium. Some companies claimed that all grinding at their establishments was carried out under wet conditions; others provided local exhaust ventilation for their grinding operations. Both "wet" and "dry" machining and grinding of copper-beryllium was observed in plant visits conducted during this study. Very little idea was gained of beryllium exposure levels encountered in these machine-shop operations. Some data are, however, available from experiments conducted under simulated machine-shop conditions. And these data indicate that breathing-zone concentrations would generally be below 1 μg Be/m^3 for both "dry" and "wet" machining, but that under adverse circumstances (e.g., use of blunt cutting tools and lack of coolant) considerably higher levels could be encountered. There are probably some 400 to 700 Ontario workers involved in machining copper-beryllium alloys.

Resistance welding, aluminum die casting, plastic injection- and blow-moulding are activities which involve the use of copper-beryllium as a tool component. This use does not directly lead to worker exposure to airborne beryllium, but the attendant maintenance activities (refacing resistance-welding electrodes, refurbishing die-casting plunger tips, and repair of moulds) can require machining of the copper-beryllium components. There are also a number of operations which consist solely of assembly of copper-beryllium components. There will be no exposure to atmospheric beryllium in these activities. Forming operations on copper-beryllium alloys (e.g., fabrication of electrical connectors, production of copper-beryllium springs) are other activities which would not result in atmospheric beryllium exposure. The number of Ontario workers who merely handle copper-beryllium products (as opposed to workers who handle and machine or cast the alloy) would be in the range of 2500 to 3500. The majority are employed in the automobile industry.

INDUSTRY'S PERCEPTIONS AND OPINIONS

No particular or pressing problems regarding the use of beryllium and its compounds were expressed by either labour or management representatives contacted during this study.

Industries handling beryllium metal (precision machining and Candu fuel-rod manufacture) appeared to have a realistic awareness of the potential hazards of beryllium exposure. There was confidence that the precautions and procedures already adopted by these industries would be adequate for any designated substance regulation the government might want to introduce. None of the industries' representatives had any problem with a time-weighted average exposure value of 2 μg Be/m^3, but one individual indicated that an exposure limit of 0.5 μg Be/m^3 (as had, for example, been recommended by NIOSH) would pose problems.

There seems to be a certain resistance in the microelectronics industry to the use of beryllia as a substrate material for microcircuits. This reluctance was coupled with a heightened awareness of the potential hazards associated with handling the material in the microelectronic environment. Nonetheless, there was confidence among the few companies which used, or were planning to use, beryllia that precautions currently employed in the industry for handling the ceramic would be sufficient to ensure compliance with any designated-substance type regulation the government might decide to implement.

There was less of a consensus among the different industries which use beryllium alloys. Perhaps a majority viewed beryllium exposure in their operations as presenting no hazard or as having a very low hazard potential. But certain activities (e.g., welding and dry grinding) were recognized as having a moderate hazard potential. No specific comments regarding either designation or appropriate exposure limits were received; rather remarks centered on procedure-related options. There was widespread acknowledgement, that machining and grinding of copper-beryllium should be carried out using coolants and cutting fluids. But such practices did not always occur despite company rules.

REGULATORY CONSIDERATIONS

The TWAEV of 2 μg Be/m^3 mandated under Ontario's *Regulation Respecting Control of Exposure to Biological or Chemical Agents* [O. Reg. 654/86] is consistent with the ACGIH TLV® guidelines and the occupational exposure standards of most foreign and domestic jurisdictions examined during this study. Some countries, however, have adopted more stringent exposure standards (e.g., 1 μg/m^3 in Czechoslovakia, Denmark and the U.S.S.R., and 0.5 μg/m^3 in Israel). Along with the ACGIH, most jurisdictions classify beryllium and its compounds as suspected carcinogens and usually attendant with this classification are specific work-practice and ventilation-control stipulations. Beryllium and its compounds are not, however, classified as carcinogens under Ontario regulations. But such a classification could, in principle, be effected by adding beryllium and its compounds to the Part 10 list of known toxic agents in the Exposure Control Regulation [O. Reg. 654/86], because the majority of 15 substances already on the list are either proven or suspected human carcinogens. If this course were adopted, however, the TWAEV requirements would be replaced by the more stringent requirement that "any exposure" to beryllium "should be avoided".

If the scope of the Exposure Control Regulation was considered insufficient to ensure adequate worker protection, a Designated Substance Regulation might be considered as a more stringent alternative. It could be argued, however, that such a regulation should exempt industries or processes using copper-beryllium alloys and focus on those workplaces using pure beryllium and materials with high beryllium content. Industries using beryllium are small in number and relatively sophisticated technologically, hence a focussed program of engineering controls (such as might be required under a Designated Substance Regulation) could be an effective and efficient means of reducing beryllium exposure. Because of what is known about the health effects of beryllium (latency, individual susceptibility and suspected carcinogenicity) a medical surveillance program for certain workplaces, such as might be mandated under a Designated Substance Regulation, could also be an option worth considering.

The introduction of WHMIS in October 1988 will increase the availability of information regarding hazardous materials and, ideally, will ensure through required education programs that workers better understand the hazards that the use of such materials present. The WHMIS provisions largely obviate the need to introduce specific regulatory requirements for training and education (e.g., through a Designated Substance Regulation for beryllium) which might otherwise have been deemed necessary under the present provisions of the Occupational Health and Safety Act.

1. INTRODUCTION

Given that beryllium and beryllium compounds have one of the most stringent occupational exposure limits of all hazardous agents in Ontario workplaces (a TWAEV of 2 $\mu g/m^3$, measured as beryllium [1]), it is perhaps ironic to reflect that the alternative name for beryllium, *glucinium,*[*] refers indirectly to the fact that salts of the element have a distinctly sweet taste. Some 150 years after the original taster's dulcet discovery (Vauquelin, 1798 [3]), beryllium compounds gained notoriety as the first inorganic substances shown experimentally to be carcinogens when it was reported that osteosarcomas developed in rabbits intravenously administered either beryllium zinc silicate or beryllium oxide [4]. In the same year, the first North American evidence was published linking a chronic lung disease (berylliosis) with occupational exposure to beryllium compounds. This evidence was a report of 17 persons who contracted the disease and were employed in the fluorescent lamp industry; an industry where beryllium compounds (e.g., beryllium zinc silicate) were used as fluorescent coatings [5]. Beryllium compounds are no longer used in fluorescent tubes, but beryllium-containing materials may be found in anything from nuclear reactors and spacecraft to truck parts and ballpoint pens.

1.1 BERYLLIUM-CONTAINING MATERIALS IN ONTARIO

There is no primary production or processing of beryllium ore in Ontario or indeed in Canada. The three classes of beryllium-containing materials used industrially are beryllium metal, beryllia (beryllium oxide), and beryllium alloys. But, with the exception of a small quantity of copper-beryllium and aluminum-beryllium alloys (made from imported master alloys), none of these materials are themselves produced in Canada.

The flow of beryllium materials within Ontario industry is shown in Figure 1-1. The largest users tend to import beryllium stock directly from the major suppliers in the United States; the occasional or low-volume users, on the other hand, are more likely to buy

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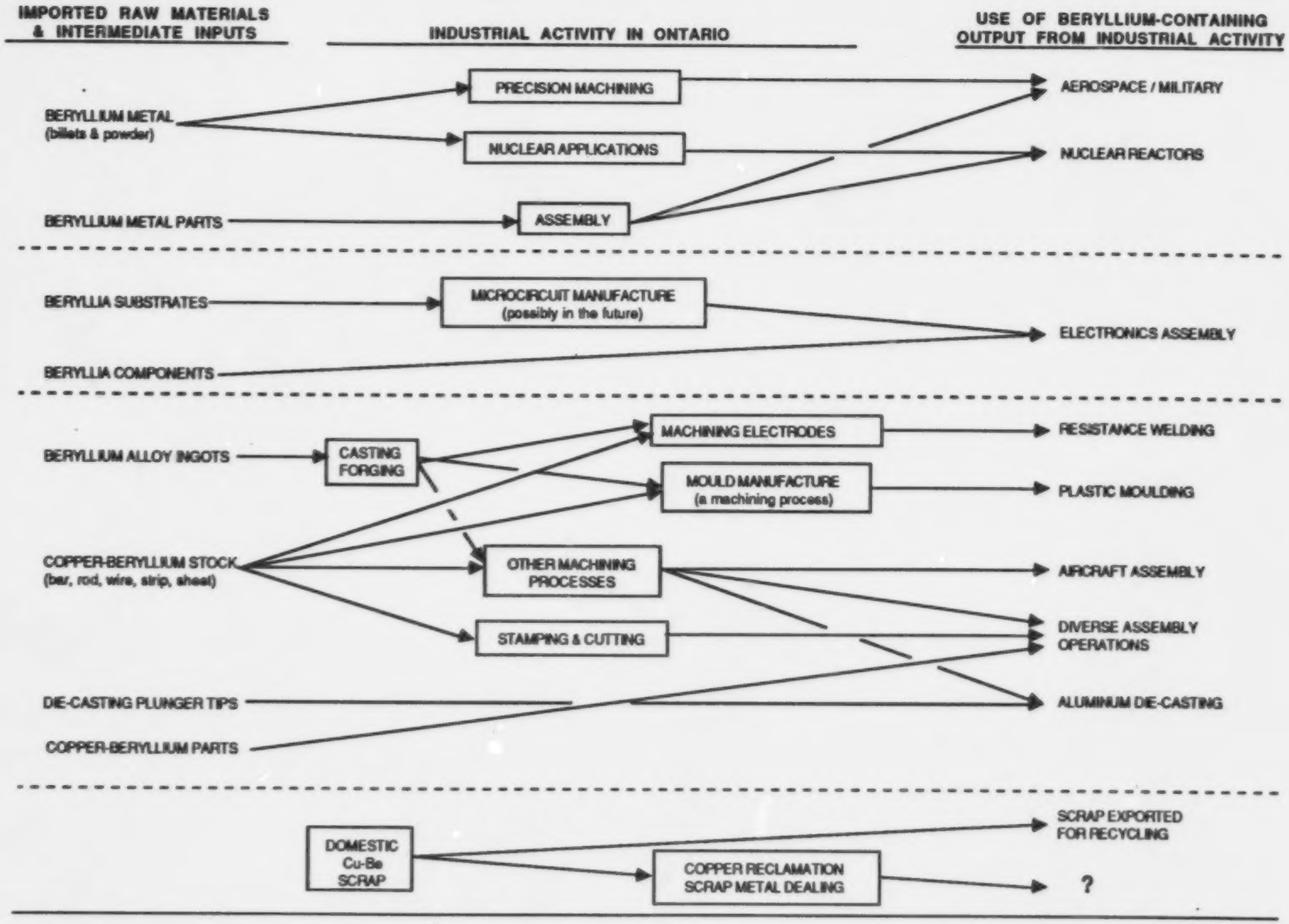
[*] Since the isolation of the pure metal in 1828 (by Wohler, who called the element "beryllium", and by Bussy, who called it "glucinium") the name "glucinium" was quite widely used, especially in Europe. In 1957, however, the International Union of Pure and Applied Chemistry (IUPAC) officially pronounced "beryllium" to be the name of this first member of the alkaline-earth group of elements. [2]


IMPORTED RAW MATERIALS & INTERMEDIATE INPUTS
INDUSTRIAL ACTIVITY IN ONTARIO
USE OF BERYLLIUM-CONTAINING OUTPUT FROM INDUSTRIAL ACTIVITY
BERYLLIUM METAL (billets & powder)
PRECISION MACHINING
AEROSPACE / MILITARY
NUCLEAR APPLICATIONS
NUCLEAR REACTORS
BERYLLIUM METAL PARTS
ASSEMBLY
BERYLLIA SUBSTRATES
MICROCIRCUIT MANUFACTURE (possibly in the future)
ELECTRONICS ASSEMBLY
BERYLLIA COMPONENTS
MACHINING ELECTRODES
RESISTANCE WELDING
BERYLLIUM ALLOY INGOTS
CASTING FORGING
MOULD MANUFACTURE (a machining process)
PLASTIC MOULDING
COPPER-BERYLLIUM STOCK (bar, rod, wire, strip, sheet)
OTHER MACHINING PROCESSES
AIRCRAFT ASSEMBLY
STAMPING & CUTTING
DIVERSE ASSEMBLY OPERATIONS
DIE-CASTING PLUNGER TIPS
ALUMINUM DIE-CASTING
COPPER-BERYLLIUM PARTS
DOMESTIC Cu-Be SCRAP
SCRAP EXPORTED FOR RECYCLING
COPPER RECLAMATION SCRAP METAL DEALING
?

NOTE: This flow diagram was constructed from knowledge gained during the study.

FIGURE 1-1 The Flow of Beryllium-Containing Materials in Ontario Industry

through Canadian-based metal suppliers. In some industrial activities (e.g., aluminum die casting), both imported finished parts and parts fabricated in-house from imported copper-beryllium stock are used.

Although we were unable to obtain direct evidence for the amounts of beryllium-containing materials used by Ontario industry, it proved possible to estimate the quantities involved [Appendix II]. The estimates, based on published trade figures and on experience gained during the study, suggest that 3.5 to 6 tonnes of beryllium alloys (predominantly copper-beryllium) and 220 to 270 kg of pure beryllium are consumed annually in Ontario. The quantities of beryllia currently used are very small and are probably less than 100 kg per annum.

1.2 OVERVIEW OF THE REPORT

The aim of this report is to provide a broad-ranging account of the occupational-health situation with regard to the use of beryllium-containing materials in Ontario industry. The information presented comes from a variety of sources:

- a mail-out questionnaire survey to 179 industrial establishments in Ontario representing 156 different companies [identified in Appendix I and discussed in Appendix III];
- follow-up telephone interviews of 53 of the respondents [detailed in Appendix III];
- walk-through surveys of 12 industrial establishments [identified in Appendix I];
- contacts with some 16 trade associations and labour unions by letter, telephone interview, and face-to-face meeting [identified in Appendix I]; and
- requests for information regarding regulatory approaches from 38 governmental agencies, representing 15 countries, 5 U.S. states, and 12 Canadian provinces and territories by letter or telephone [identified in Appendix I].

In addition, a variety of published material dealing with various technical, scientific and regulatory aspects of occupational exposure to beryllium was reviewed.

The report starts with an examination of the properties of beryllium-containing materials, a brief summary of the health effects which may arise from exposure to such materials, and details of methods by which occupational exposure to beryllium may be measured. This is followed, in Chapter 3, by descriptions of the types of processes involving beryllium-containing materials used by Ontario industry. Chapter 4 starts with a discussion of the various measures which are used to control occupational exposure to beryllium and its compounds, and concludes with estimates of the numbers of workers who handle and may be exposed to the materials. A human dimension is provided in Chapter 5 by focussing on the opinions and perceptions of both labour and management representatives with regard to occupational health aspects of beryllium-containing materials. The report concludes with a discussion in Chapter 6 of regulatory control of occupational exposure to beryllium and its compounds.

The report should be regarded as a background overview of many of the issues, regulatory and otherwise, raised by worker exposure to beryllium. It is hoped that this report will be of use in the Ministry's assessment of the various implications of options currently available for control of worker exposure to beryllium and its compounds.

2. PROPERTIES, HEALTH EFFECTS AND MEASUREMENT

The summaries in this chapter provide necessary background information to the discussions on occupational health aspects of the use of beryllium-containing materials presented in the remainder of this report. The physical and chemical properties dictate the uses to which the materials are put [uses which are detailed in Chapter 3]. A knowledge of potential health effects arising from occupational exposure to the materials provides both a perspective to the descriptions of exposure situations in Ontario industry [Chapters 3 and 4] and a context for a discussion of the different regulatory approaches adopted by domestic and foreign jurisdictions [Chapter 6]. And methods for measuring occupational exposure are integral to the control of such exposure, both from a work-practice perspective [Chapter 4] and from a regulatory viewpoint [Chapter 6].

2.1 PROPERTIES

The only beryllium-containing materials commonly used in Ontario industry are the metal itself, the oxide (beryllia or beryllium oxide), and beryllium alloys (predominantly copper-beryllium). Some of the physical properties of these materials are presented in Table 2-1.

2.1.1 Beryllium Metal

Beryllium is a silver-grey metal chemically similar to aluminum. It is quite resistant to atmospheric oxidation at ambient temperatures, but is susceptible to corrosion by salt water. Beryllium reacts readily with sulphuric and hydrochloric acids, but is passivated by concentrated nitric acid and is only slowly attacked by the dilute acid. The metal is also readily attacked by hot concentrated alkalis, yielding the amphoteric hydroxide, $Be(OH)_2$. [2]

The combination of lightness, stiffness and dimensional stability (Young's modulus of elasticity for beryllium is greater than that for steel [10]) makes pure beryllium unique for a number of specialist applications — mainly in the aerospace and military hardware fields. The ability of beryllium to form a eutectic alloy with zirconium is a critical feature in

TABLE 2-1 Some Physical Properties of Beryllium, Beryllia and Copper-Beryllium

Property	Beryllium [2]	Beryllia	Copper-Beryllium Alloy 25 [8] (1.8 to 2.0% Be)	Copper-Beryllium Alloy 174 [9] (0.15 to 0.5% Be)
melting point	1287 to 1292°C	2530°C [6]	870 to 980°C	1025 to 1065°C
boiling point	2970°C	3900°C [6]	n/s	n/s
density @ 25°C	1.85 $g.cm^{-3}$	3.008 $g.cm^{-3}$ [6] *2.85 to 2.90 $g.cm^{-3}$ [7]	8.36 $g.cm^{-3}$	8.80 $g.cm^{-3}$
thermal conductivity (at room temp., ~25°C)	1.9 $W(cm.°C)^{-1}$	3 $W(cm.°C)^{-1}$ [7]	1.0 $W(cm.°C)^{-1}$	2.0 to 2.6 $W(cm.°C)^{-1}$
electrical conductivity (at room temp., ~25°C)	2.3×10^5 mho.cm	~10^{-15} mho.cm [7]	1.3×10^5 mho.cm	~2.5×10^5 mho.cm

[ ] references

* This represents the normal range of densities found in the commercially available sintered ceramic.

n/s not specified in the reference cited.

the manufacture of nuclear fuel bundles for nuclear reactors. And the neutron reflecting properties of pure beryllium find use both in nuclear reactors and in nuclear weapons. [2]

2.1.2 Beryllia

Beryllia is commercially available as a sintered ceramic. Its high melting point and chemical inertness make it a useful refractory material. It is, however, the combination of high thermal conductivity with very low electrical conductivity which provides its major commercial usefulness in electrical and electronic applications. As the leading manufacturer of beryllium and beryllium compounds explains [7]:

> Beryllia's thermal conductivity is 10 times greater than alumina (or approximately equal to aluminum metal), making it useful in heat producing circuits, such as those carrying high currents or very dense circuitry. Beryllia's low dielectric constant allows improved electric performance, particularly at higher frequencies.

Beryllia is, for example, now being used in automotive electronic ignition systems and in portable and mobile communication systems (cellular telephones are one example) [7,11].

2.1.3 Copper-Beryllium Alloys

The addition of small quantities of beryllium to copper (usually together with small amounts of cobalt) has the property of strengthening the copper while still retaining the desirable heat and electrical conductivity properties of the metal. Copper-beryllium alloys (which are essentially ternary alloys of copper, beryllium, and cobalt, with traces of other elements) have unique characteristics that lead to a variety of applications, some of which are indicated in Table 2-2. The most important characteristics of the alloys are high electrical and thermal conductivity, and the ability to be hardened to tensile strengths comparable to those of many high-strength steels. High-conductivity alloys and high-strength alloys are the two main categories of copper-beryllium alloys and differ in the relative proportions of beryllium to cobalt (the former having a lower beryllium content and a higher cobalt content than the latter). [2]

Copper-beryllium is resistant to corrosion by a wide variety of substances: salt water, most organic acids (including acetic acid), hydrochloric acid, dilute sulphuric acid, phosphoric acid, and aqueous solutions of sulphates, chlorides and carbonates [8]. The

TABLE 2-2 Copper-Beryllium Alloys[†]

Alloy Type	Be Content	Co Content	Typical Applications
HIGH-STRENGTH ALLOYS	1.6 to 2.0%	~0.25%	* small electric contacts * springs * clips and fastenings * switches * bellows Bourdon pressure gauges non-sparking tools * blow-mould dies
HIGH-CONDUCTIVITY ALLOYS	0.3 to 0.8%	1.4 to 2.7%	* springs * switches * contacts * welding discs and tips

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[†] summarized from information presented by Ballance *et al.* [2].

[*] Applications identified by survey respondents as occurring in Ontario. (This does not necessarily imply that the activities not indicated do not occur in the province, but merely that none of the 133 respondents reported doing so.)

alloys are, however, attacked by alkalis, nitric and chromic acids, and aqueous ferric chloride. [8]

2.2 HEALTH EFFECTS

The summary presented below is based on information provided in extensive reviews carried out by the United States Environmental Protection Agency (EPA) [6] and Occupational Safety and Health Administration (OSHA) [12], but, at the request of the Ministry of Labour, we have not ourselves evaluated the original work upon which these reviews were based. A detailed assessment of occupational health effects, however, will be found in a document currently being prepared by the Ministry [13].

2.2.1 Acute Effects

Acute effects of beryllium exposure can range from contact dermatitis to fatal pneumonitis. Cases of acute poisoning were most often reported in the years prior to 1949 — the year which saw adoption of a 2 $\mu g/m^3$ TWA exposure limit and a 25 $\mu g/m^3$ ceiling limit. Since that date, the number of new cases reported has been relatively small, although they are still occurring. There is considerable evidence that a chemical hypersensitivity is a factor in some, if not most, cases of acute poisoning.

Cuts or abrasions contaminated with soluble beryllium compounds develop ulcers and abscesses which take weeks to heal. It is unclear from the reviews if such slow-to-heal ulceration is confined to contamination by water-soluble forms of beryllium or whether the effect may also be caused by such non-soluble forms as copper-beryllium alloys. Acute ocular irritation may also occur if beryllium-containing material enters the eye.

Beryllium-induced acute respiratory effects range from mild inflammation of nasal and pharyngeal mucosae, to tracheobronchial involvement and severe chemical pneumonitis. Recovery is usual and takes from one to six weeks. In a few instances, however, death has occurred between two and 10 weeks after exposure.

2.2.2 Chronic Effects

There is little argument that excessive exposure to atmospheric beryllium can cause a chronic lung disease called berylliosis. Its most familiar manifestation is a pneumonitis, with accompanying cough, chest pain and general weakness. Pulmonary dysfunction and such systemic effects as heart enlargement (leading to cardiac failure), enlargement of the liver and spleen, and the appearance of kidney stones may also be associated with what is collectively called chronic beryllium disease (CBD). The latency period between exposure and the appearance of detectable evidence of CBD normally ranges from five to 10 years, but periods of 20 years or more have also been reported. According to Nearing [13], the chronic course of the disease is variable with both remissions and exacerbations being experienced by some patients; other patients, however, may have a stable course for years. Medical treatment may also affect the progression and/or severity of the disease.

Chronic beryllium disease differs from some other occupational lung diseases in that it also has a systemic component. The systemic involvement suggests that there is an immunological component to the disease and that hypersensitivity can explain some of the findings in CBD. Prolonged dermal contact with certain beryllium compounds can lead to granulomatous skin disease. And this may be a manifestation of hypersensitivity.

The carcinogenicity of beryllium compounds to several animal species (evident particularly in lung and bone tissue) is well established. The International Agency for Research on Cancer (IARC) has concluded that there is "sufficient evidence" for beryllium to be classed as a carcinogen in animals [14]. The picture with regard to human carcinogenicity is less clear. Epidemiological studies present equivocal conclusions on the carcinogenicity of beryllium and beryllium compounds to humans, and there has been considerable debate as to whether beryllium and its compounds should be considered human carcinogens. The problem is that little is known about the mechanisms by which beryllium effects in mammals are brought about, although it has been suggested that the selective inhibition by the beryllium ion of certain protein phosphorylation reactions within cell nuclei is potentially most relevant to induction of beryllium carcinogenesis [15]. The IARC has concluded that there is "limited evidence" that beryllium and its compounds are human carcinogens [14]. But the Agency has also concluded that this evidence, taken together with the experimental animal evidence, indicates that beryllium should be suspected of being carcinogenic to humans [13]. This conclusion is echoed by the American Conference of Governmental Industrial Hygienists (ACGIH) which identifies beryllium as a "substance suspect of carcinogenic potential for man" [16].

2.3 MONITORING METHODS

The analytical basis for all forms of occupational health monitoring for beryllium is atomic absorption spectrometry. Modern methodologies employ flameless techniques (e.g., vapourization of the analyte in a graphite furnace) for generation of atomic beryllium and absorption of the 239.4 nm emission from a beryllium hollow-cathode lamp for its quantification. Flameless atomic absorption spectroscopy is more sensitive than the flame atomic absorption and plasma emission techniques used in earlier validated methods [17].

2.3.1 Air Sampling

The current method approved by the U.S. National Institute of Occupational Safety and Health (NIOSH) for the determination of airborne beryllium is NIOSH Method No. 7102 [17] which replaces the earlier, but identical, NIOSH Method No. P&CAM 288 [18]. The method is applicable for both personal and area sampling and has a working range of 0.5 to 10 μg Be/m^3 based on a 90 L sample volume.

The NIOSH procedure employs a cellulose membrane filter (0.8 micron), through which air is drawn at rates of 1 to 4 L/min, to collect airborne beryllium-containing particles. The filter is digested and ashed using nitric and sulphuric acids (10:1 volume ratio) and the residue dissolved in 10 mL of sodium sulphate (2% w/v)/sulphuric acid (3% v/v) solution. A 10 μL aliquot of the resulting solution is injected into the graphite furnace of the atomic absorption spectrometer. This technique measures the beryllium content of total suspended particulates (TSP). It is this quantity which is normally referred to in occupational exposure limits.

The major organ affected in chronic beryllium disease is, however, the lung. Accordingly, it may be of more relevance to measure beryllium in the respirable fraction of TSP. In this case, a particle-size sampler like an Anderson impactor would be used in place of a particle filter. The dust collected in the respirable-particle size stages of the sampler can be digested and analyzed for beryllium in a manner similar to that used for dust collected on particle filters. Senn investigated particle-size distributions during simulated machining of copper-beryllium and found that about 10 percent of beryllium by weight in TSP was associated with particles of respirable size [19].

2.3.2 Surface Sampling

As described later in this report [Sections 4.1.1.3 and 4.1.2.3] it is normal "housekeeping" practice for companies using pure beryllium to regularly monitor working surfaces for beryllium dust. This is accomplished by a procedure, borrowed from practices used in the nuclear industry to monitor surface radioactive contamination, known as "swipe testing". According to an early NIOSH method for beryllium monitoring (P&CAM 121), "swipe samples should be collected on Whatman filter paper by thoroughly wiping a *measured* area and placing the filter in a chemically clean jar" [20]. The beryllium dust picked up on the filter paper can then be analyzed by the same method as used for air samples.

2.3.3 Biological Monitoring

The NIOSH method for the analysis of beryllium in biological tissue (P&CAM 279) involves digesting and ashing a weighed tissue sample (~500 mg) in a mixture of nitric, sulphuric and perchloric acids (3:1:1 volume ratio) and taking up the residue with 10 mL dilute sulphuric acid (3% w/v). An aliquot (5 to 25 µL) of the sulphuric acid solution is then analyzed using flameless atomic absorption spectrometry. The working range of the method is 5 to 250 µg Be/kg of fresh tissue. [21]

This method, however, is hardly suitable for routine monitoring of beryllium exposures. More appropriate is determination of beryllium in urine, the major route by which beryllium is excreted. A simple method for this analysis is described by Grewall and Kearns [22]: A sample of urine is acidified with nitric and sulphuric acids (to final acid concentrations of 0.5% v/v and 4% v/v, respectively) and a 20 µL aliquot is analyzed by flameless atomic absorption spectrometry. The operating range of the method was reported as 0.5 to 50 µg/L of urine.

There do not appear to be sufficient data linking beryllium-exposure levels with concentrations of the element in urine to permit the use of urinalysis as a quantitative measure of beryllium exposure. Nonetheless, detection of abnormally high concentrations of beryllium in urine can be indicative of occupational exposure and, indeed, urinalysis for beryllium is used by some Ontario companies in regular medical examinations of their employees. Average beryllium concentrations in non-exposed individuals have been reported as 0.9 µg/L both for 120 individuals in the Los Angeles area of the United States [22] and for 20 individuals in Germany [23].

In the past, patch testing had been used to detect individuals who were hypersensitive to beryllium. These tests are no longer used because: 1) they may cause a reactivation of latent beryllium disease, 2) they may have other adverse health effects, and 3) such tests may produce misleading results [13]. Currently, lymphoblast transformation is regarded as the most useful test to detect hypersensitivity in humans [6].

2.4 SUMMARY

The only beryllium-containing materials enjoying significant commercial use in Ontario are the metal itself (in both billet and powder forms), beryllia (as a sintered ceramic), and beryllium alloys (predominantly copper-beryllium). These materials all have similarly good thermal conductivities. The metals (pure beryllium and beryllium alloys) possess good electrical conductivity and are comparatively resistant to corrosion. Beryllia is an excellent electrical insulator and is chemically inert.

There are a number of adverse health effects associated with exposure to beryllium and its compounds, some (and maybe most) of them mediated by a latent hypersensitivity to beryllium in some individuals:

- contact dermatitis;
- acute irritation in eyes contaminated by beryllium-containing material;
- ulceration of cuts contaminated by soluble beryllium compounds;
- chronic skin and other systemic granulomatous skin diseases; and
- acute and chronic lung diseases — forms of pneumonitis in their most severe manifestations (the chronic disease, berylliosis, exhibits latency periods of up to twenty years).

The IARC and the ACGIH both recommend that beryllium be considered suspect of being carcinogenic to humans.

Atomic absorption spectrometry is the analytical technique used to monitor occupational exposure to beryllium and can be used both for air and surface samples, and for the measurement of beryllium excreted in the urine of exposed individuals. Urinalysis for beryllium is not, however, considered a reliable quantitative measure of beryllium exposure. It can merely indicate that exposure might have occurred. Lymphoblast transformation is regarded as the most useful test to detect beryllium hypersensitivity in humans.

3. MANUFACTURING OPERATIONS INVOLVING BERYLLIUM OR ITS COMPOUNDS

This chapter provides an overview of the operations which involve beryllium-containing materials in Ontario manufacturing. The materials are used for a multiplicity of applications under a variety of conditions. This diversity leads to situations where the potential for exposure extends over a wide range — from the very high (e.g., the handling of finely divided beryllium) to the non-existent (e.g., mere assembly of parts containing fractions of a percent of beryllium).* More than one type of operation involving beryllium-containing materials may be found in the same manufacturing plant and a particular operation may be used in more than one industry. In most cases, the use of beryllium or its compounds plays only a small part in an establishment's manufacturing operations. For all these reasons, it is easier (and, from an occupational health standpoint, more appropriate) to deal with the industrial uses of beryllium and its compounds from a process-orientation perspective rather than on an industrial-sector basis.

3.1 OPERATIONS INVOLVING BERYLLIUM

The expense of pure beryllium (about $600/kg [Appendix II]) limits the use of the metal to applications where its properties make it uniquely suitable. As a consequence, beryllium is used by only a small number of Ontario companies.

3.1.1 Precision Machining

We are aware of two companies which machine beryllium metal. The items produced (e.g., gyroscope assemblies for inertial navigation systems, parts for a speciality camera) are small, comparatively complex, and have to be fabricated to very close tolerances, often to within a few ten thousandths of an inch. The equipment used in manufacturing such items includes miniature lathes, grinders and drill presses, and a considerable amount of hand work is involved. In one process sand blasting is used to make grooves on beryllium surfaces. In addition to the manufacture of beryllium parts and their assembly into finished products, inspection and maintenance of beryllium-containing equipment is carried out in the same facility. The photographs presented in Figure 3-1 give an idea of the equipment used in the machining of beryllium metal and in the assembly and maintenance of the final products.

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* It must be stressed that we are referring to the potential for exposure and not the actual worker exposure. As may be seen from information presented in Chapter 4, where a high exposure potential exists (e.g., certain operations involving beryllium or beryllia), industrial hygiene practices are very thorough and worker exposure may actually be as low as in operations with a much lower exposure potential (e.g., machining of copper-beryllium alloy).

3.1.2 Welding of Spacers on Fuel Rods for Candu Nuclear Reactors

A Candu fuel rod consists of a tube of zirconium alloy (zircaloy) containing cylindrical pellets of uranium dioxide. The tube is some 50 cm long, about 15 mm in diameter, and has a wall thickness of about 0.4 mm. The fuel rods are arranged in a cylindrical array known as a fuel bundle. The bundle contains 28 or 37 rods depending on reactor type. Zircaloy spacers brazed to the fuel-rod cladding prevent adjacent rods in the fuel bundle from touching when subjected to stresses in the operating reactor.*

The spacers, which have widths and heights of 2 to 3 mm and lengths varying from about 1 to 3 cm, have to be securely attached to the fuel-rod sheath. The problem is that the zircaloy tubing is very thin and subject to distortion in normal welding or brazing. Beryllium, however, has the ability to form a eutectic weld with zirconium since a mixture of zirconium and beryllium melts at a lower temperature than either of the two metals alone. Thus, if the spacer is coated with beryllium, it may be brazed to the fuel sheath at temperatures below the softening point of zircaloy and, hence, tube deformation can be avoided.

Two companies in Ontario manufacture fuel bundles for Candu reactors. Although in general terms the same manufacturing process is used by both companies [Figure 3-2], there are differences in the details. These differences are especially obvious in the approaches adopted in the production and preparation of the spacers prior to the final brazing step. Because both companies regard details of their processes as proprietary information only a general outline can be given here.

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* If fuel rods touch, the flow of heavy water (which acts both as a primary coolant and a neutron moderator) is restricted and "hot spots" develop in the fuel rods. These hot spots could rapidly lead to failure of the zircaloy cladding surrounding the uranium fuel and, consequently, to the release of radioactivity into the primary coolant circuit.

3.1.2.1 Beryllium coating: The zircaloy spacer substrate is coated with beryllium using a vapour deposition process. The items to be coated are placed in a vapour deposition chamber and the beryllium is inserted in the chamber's evaporator. The chamber is then evacuated and the beryllium is rapidly evaporated by heating it electrically. This flash evaporation coats the zircaloy substrate with a thin but adherent layer of beryllium. The chamber is brought up to atmospheric pressure and the coated zircaloy is removed.

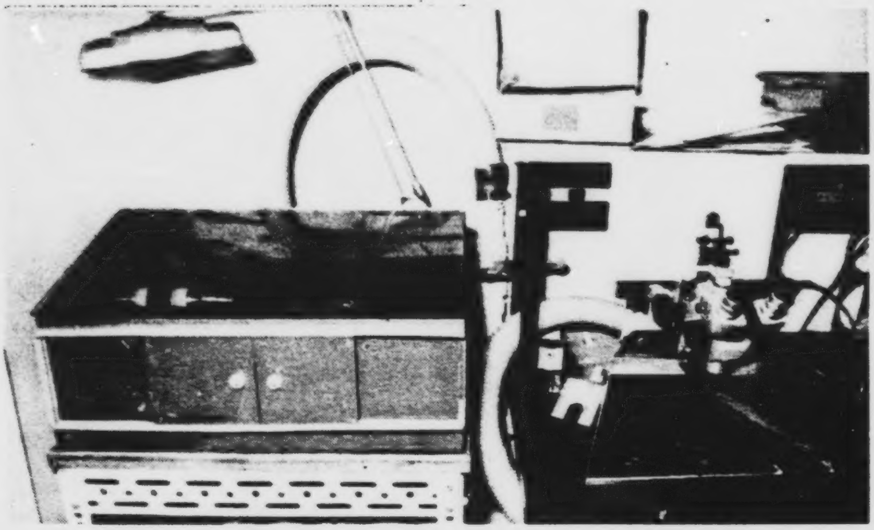
3.1.2.2 Tack welding: The spacers have to be placed in precisely defined positions on the zircaloy tube. Using a position-locating jig, the appropriate spacer (beryllium side down) is placed on the zircaloy tube and tack welded into position. The process is repeated for each spacer. (The number, size, and position of spacers on each tube depends on the position that the tube is to have in the fuel bundle.)

3.1.2.3 Brazing: The zircaloy tubes with the spacers attached are placed in a glass-walled chamber which is then evacuated. Radio-frequency power is applied through the walls of the vacuum chamber. The power is sufficient to braze the beryllium-coated spacers to the tubes, but is not enough to unduly soften the surrounding zircaloy.

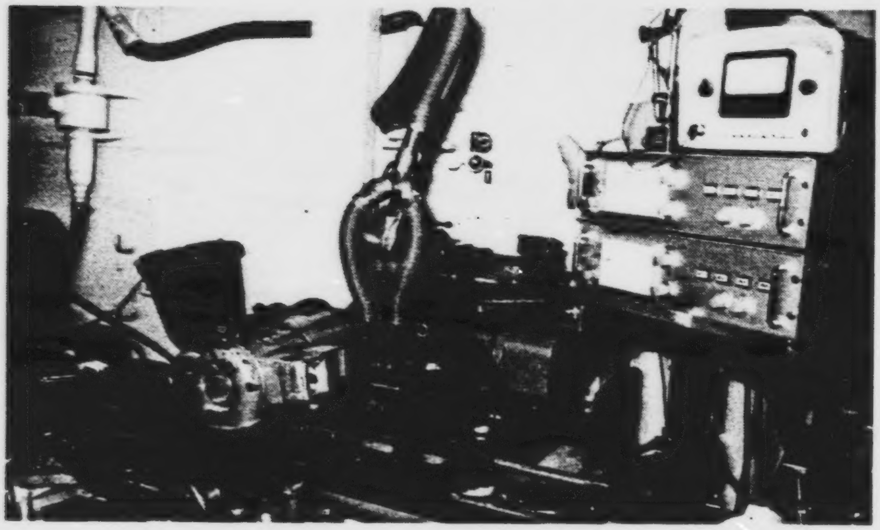
3.1.3 Assembly of Beryllium Parts

In addition to the operations described in the preceding sections, we were able to identify a couple of other operations in which beryllium was involved.

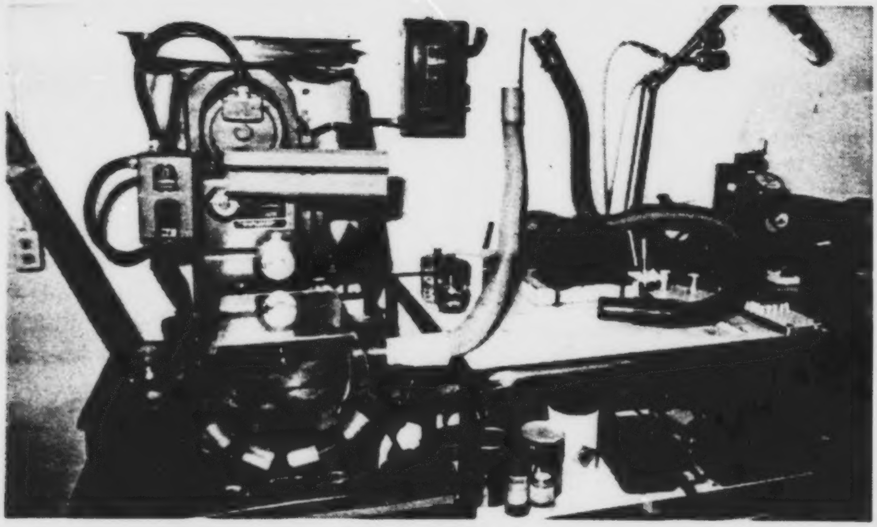
A company in Ontario produces, among a variety of radiological products, a small research reactor. This reactor, which was designed in Atomic Energy of Canada's research laboratories at Chalk River, is of an inherently safe design and employs a sub-critical mass of uranium fuel as its core. In order to create a self-sustaining chain reaction, neutrons which would normally escape from the core have to be reflected back into it. This is accomplished by placing a beryllium reflecting shield around the core. The shield is not



a) Watchmaker's lathe in exhaust box and inspection microscope fitted with high-speed exhaust.

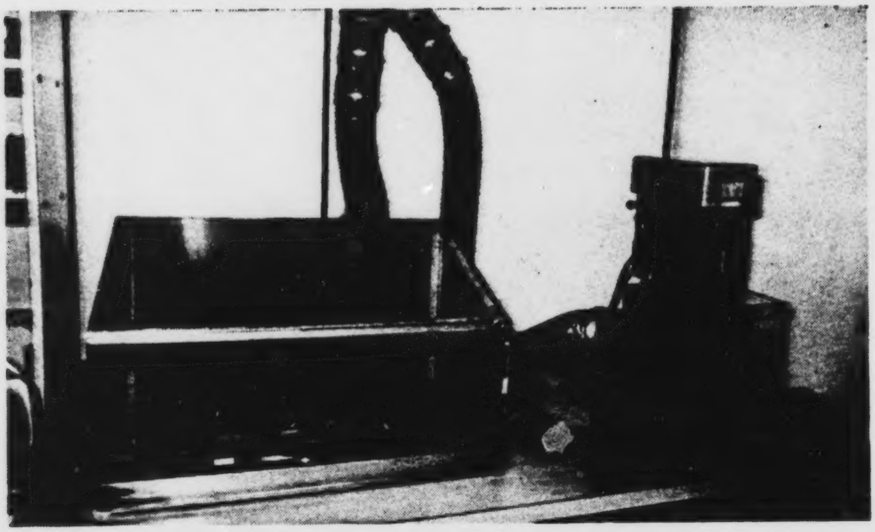


b) Grinder with workhead exhaust.



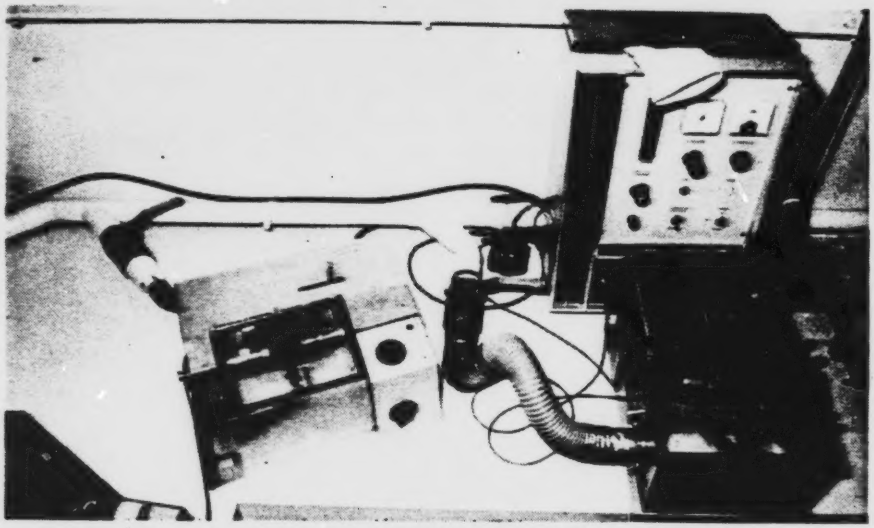
c) Honing machine exhaust.

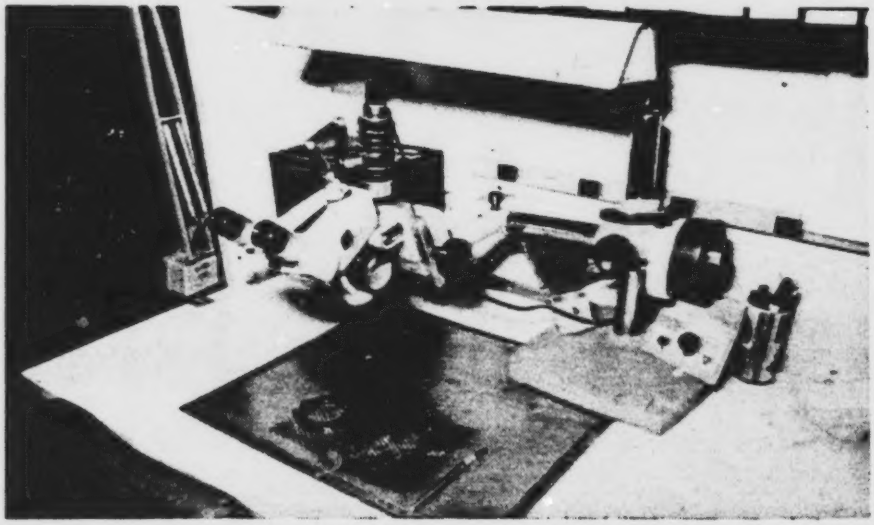
FIGURE 3-1 Examples of Equipment Used in the Machining of Beryllium



d) Surface plate inside exhausted hood and completely shrouded drill.

e) Two sand-blast units used for making grooves in beryllium surfaces.





f) Bench in dis-assembly area supplied with a high-speed exhaust grille.

FIGURE 3-1 (Cont'd.)

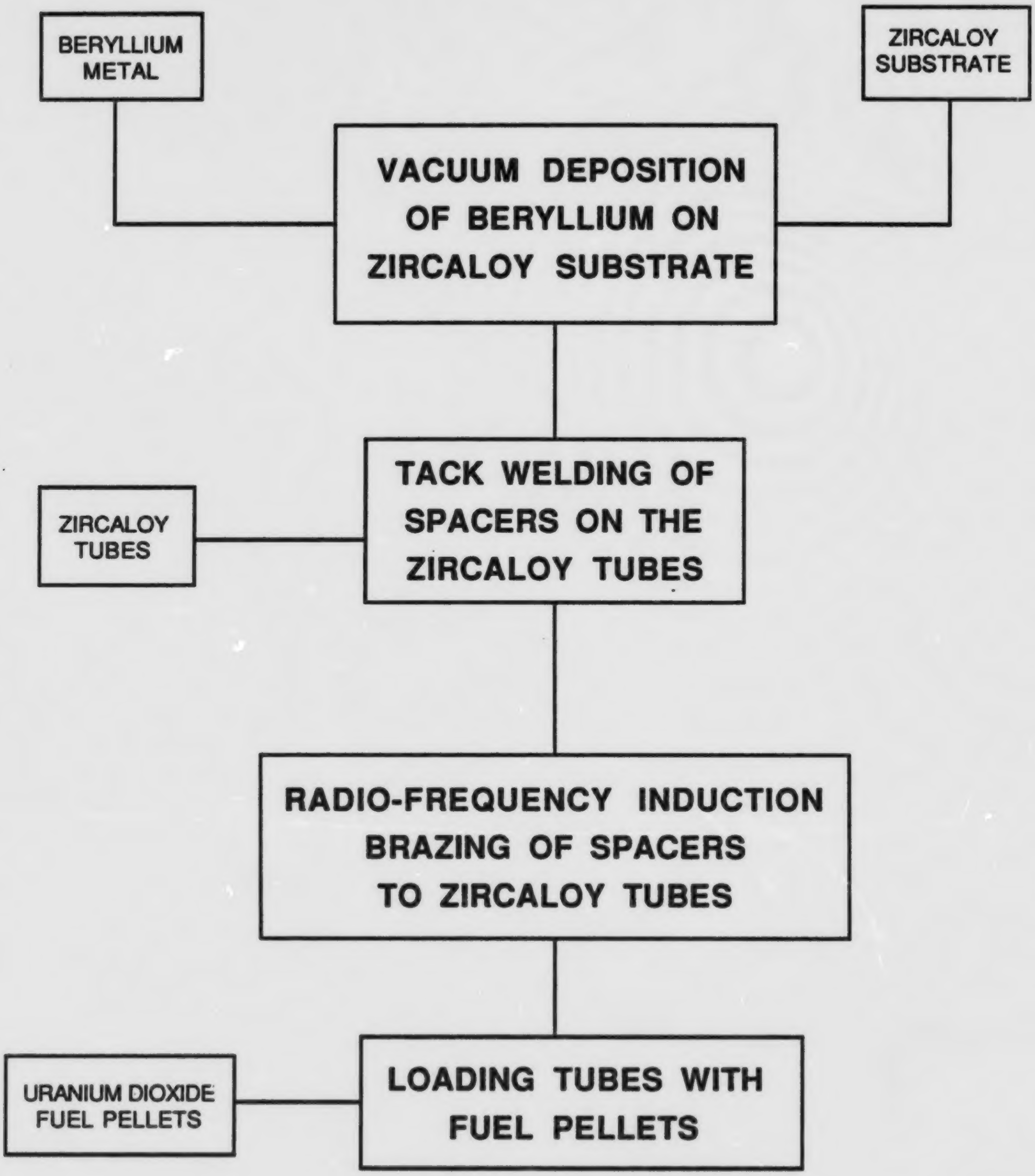

BERYLLIUM METAL
ZIRCALOY SUBSTRATE
VACUUM DEPOSITION OF BERYLLIUM ON ZIRCALOY SUBSTRATE
ZIRCALOY TUBES
TACK WELDING OF SPACERS ON THE ZIRCALOY TUBES
RADIO-FREQUENCY INDUCTION BRAZING OF SPACERS TO ZIRCALOY TUBES
URANIUM DIOXIDE FUEL PELLETS
LOADING TUBES WITH FUEL PELLETS

FIGURE 3-2 Manufacturing Steps Involving Beryllium Used in Producing a Candu Fuel-Rod

manufactured by the Ontario company but it is fabricated for it by a company in the United States. No machining of the imported shield is necessary when the reactor is constructed.

Another Ontario company had used a beryllium part in the manufacture of one of their products, but this is no longer being done. The item, a satellite reflector, was assembled into an aerospace component that the company was producing. The process involved cutting strips from a thin sheet of beryllium using metal shears. The strips were then assembled into the satellite reflector.

3.2 OPERATIONS INVOLVING BERYLLIA

Beryllia is a ceramic material used mainly in electronic packages and substrates. For certain electronic applications, beryllia is preferred to the much more commonly used alumina ceramics because of its considerably higher thermal conductivity.

We are not aware of any companies in Ontario currently manufacturing microcircuits directly on a beryllia substrate.* But two companies that carried out assembly processes involving beryllia components were identified.

3.2.1 Hybrid Microcircuit Manufacture

The vast majority of hybrid circuits are manufactured on alumina substrates. Beryllia, which is reportedly two to three times more expensive than alumina [24], is used when circuit requirements make it necessary. Representatives of one hybrid circuit manufacturer contacted during the study indicated that, while their company did not at present manufacture circuits on beryllia, the company was considering doing so in the future. For this reason it is worth giving a brief description of the process which would be involved.

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* As an exhaustive survey was not conducted [Appendix III], it cannot be said for certain that there are no companies manufacturing such circuits in Ontario. But if there are indeed any, it is unlikely that there are more than one or two.

The steps involved in the production of a hybrid microcircuit [Figure 3-3] are the same whether alumina or beryllia is the substrate. Of concern in this report are those steps which might have the potential of causing worker exposure to beryllia. These steps are, in addition to unpacking and inspection of beryllia substrates (see Section 3.2.2), laser scribing, laser trimming and separation of substrates.

3.2.1.1 Laser scribing: Commonly, a number of identical circuits are produced on a single wafer of ceramic (these wafers come in a number of standard sizes, such as 2" x 2" or 4" x 4", and are about 0.05" thick). Each individual circuit would occupy typically a fraction of a square inch of the ceramic wafer (0.5" x 0.75" for example). Prior to building up the hybrid circuit array, the ceramic wafer would be laser scribed into the individual circuit segments. The scribing process is carried out with a computer controlled pulsed laser. The laser punches a series of closely spaced holes (a few thousandths of an inch in diameter) about half way through the substrate. A grid pattern is formed upon which the array of microcircuits can be built up. This scribing enables the individual circuits to be snapped off the ceramic wafer [Section 3.2.1.3].

Of all the stages in hybrid microcircuit manufacture, laser scribing has the potential for generating the greatest amount of airborne beryllia. The laser, in punching a hole in the substrate, essentially vapourizes the ceramic.

Before the circuits are deposited on the scribed substrate, the ceramic wafer may be cleaned in an ultrasonic bath. The purpose of the cleaning is primarily to remove dirt, fingerprints, and other contaminants from the ceramic surface, but particles of the ceramic which may have remained adhering to the substrate surface after laser scribing will also be effectively removed. Ultrasonic cleaning may also be carried out at other stages during circuit manufacture.

3.2.1.2 Laser trimming: The major components of microcircuits are conductors, dielectrics and resistors which are deposited in successive stages on the substrate. It is often necessary to remove some of the deposited resistive material in order to produce a microcircuit which will perform within its design tolerances. This removal is accomplished by a computer controlled laser [Figure 3-4a] and the technique is called laser

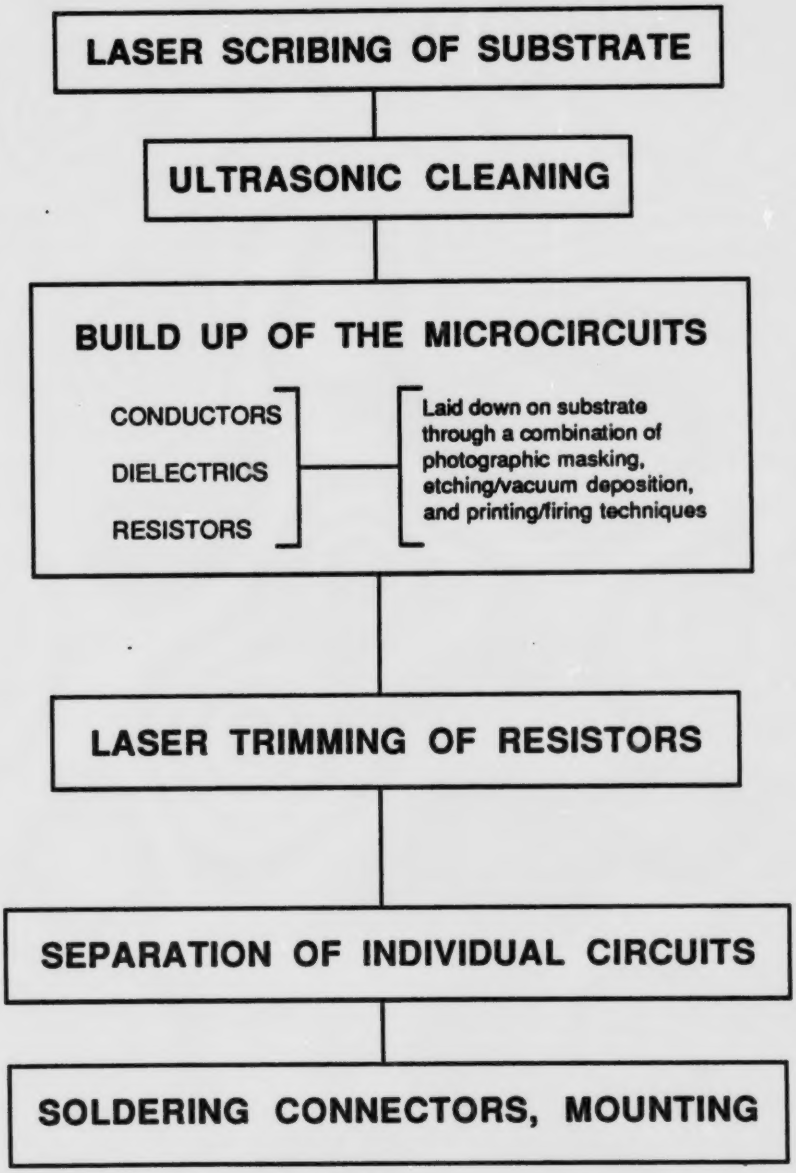
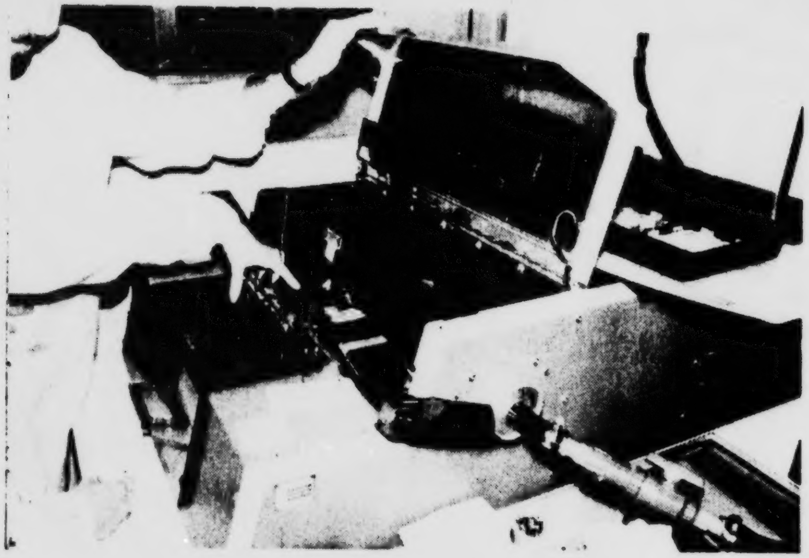
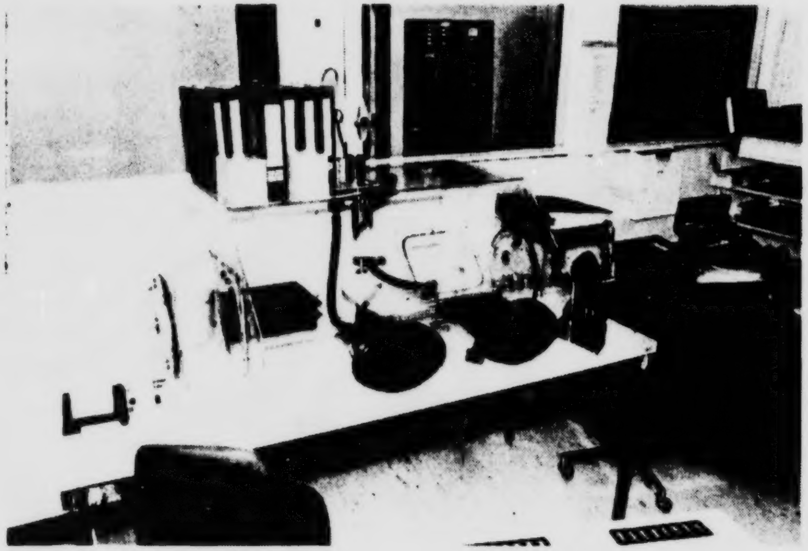

LASER SCRIBING OF SUBSTRATE
ULTRASONIC CLEANING
BUILD UP OF THE MICROCIRCUITS
CONDUCTORS
DIELECTRICS
RESISTORS
Laid down on substrate through a combination of photographic masking, etching/vacuum deposition, and printing/firing techniques
LASER TRIMMING OF RESISTORS
SEPARATION OF INDIVIDUAL CIRCUITS
SOLDERING CONNECTORS, MOUNTING

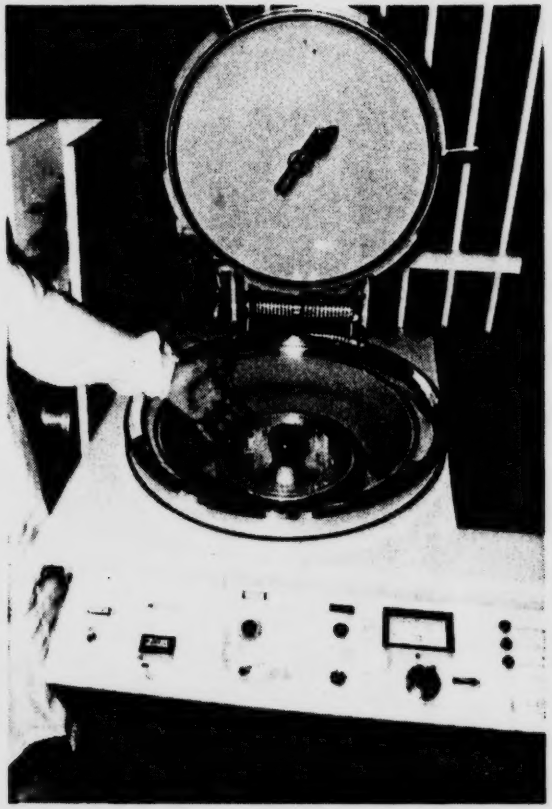
FIGURE 3-3 Typical Steps in Manufacture of Hybrid Microcircuits



a) Laser resistor trimmer (note ventilated enclosure).



b) Glove box for inspecting and handling beryllia substrates.



c) Centrifuge for stress testing of assembled circuits.

FIGURE 3-4 Examples of Equipment Used in a Beryllia Handling Facility

trimming. Resistors can be trimmed both during the manufacture of the circuit and in a final "tuning" of the completed circuit.

Unlike laser scribing, the removal of substrate material is not the aim in laser trimming. In the trimming of resistors on alumina substrates, however, the laser actually etches the alumina to a depth of 5 μm; this etching does not appear to occur when laser trimming on beryllia substrates [25]. The generation of airborne beryllia is therefore likely to be minimal.

3.2.1.3 Separation of circuits: One of the final stages in microcircuit production is to separate the array of circuits on the substrate wafer into the individual circuits. This is done manually by snapping the substrate along the scribing lines. There is the potential for small fragments of beryllium to be released during this operation.

3.2.2 Assembly Operations

One of the companies contacted produces a hybrid circuit mounted on a base of beryllia. The circuit consists of semiconductors and other components attached to the beryllia substrate using low temperature solder. The beryllia substrate is supplied by the company's customer in a finished form and all the company has to do is to mount the circuit components (i.e., there are no laser scribing and trimming operations). The substrates received from the customer are unpacked from the shipping container in a glove box operated at a slight negative pressure [Figure 3-4b] and each substrate is individually inspected. Any defective substrates (e.g., broken, chipped or cracked) are bagged in polyethylene and shipped back to the customer for replacement. Each substrate passing inspection is vacuumed to remove any beryllia dust which may be present on the surface* before being transferred from the glove box to the circuit assembly facility. The completed device is stress tested in a centrifuge [Figure 3-4c] to assure physical integrity. There is a slight chance that the device may shatter during this test, an event which would result in beryllia fragments being dispersed in the centrifuge.

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* This clean-up serves two purposes: to prevent beryllia dust from being tracked from the glove box into the rest of the manufacturing facility and to prevent dust particles from being carried on the substrate surface into the clean-room circuit-assembly area.

Another company uses beryllia washers to isolate a power supply in a piece of equipment manufactured by the company. The washers are received pre-cleaned and individually sealed in polyethylene envelopes. Because these washers are used without further processing, the potential for the release of airborne beryllia is negligible.

3.3 OPERATIONS INVOLVING BERYLLIUM ALLOYS

By far the most common beryllium-containing materials used in Ontario industry are beryllium alloys — 93 percent of all survey respondents using beryllium-containing materials reported that beryllium alloys were employed in some aspect of their operations [Appendix III]. Some aluminum and magnesium casting alloys contain small amounts of beryllium (the beryllium being added to improve casting fluidity and to decrease oxidation losses [2]) and there appears to be some slight use of such alloys in Ontario (about two percent of survey respondents using beryllium-containing materials [Appendix III]). Nickel-beryllium alloys are used for mechanical and electrical/electronic components that are subjected to elevated temperatures, and which require good spring characteristics at these temperatures [26]. Although these alloys are available for sale in Ontario [27], none of the companies responding to our mail-out questionnaire survey reported using nickel-beryllium.[*] The most important beryllium alloys, however, are those with copper — 89 percent of the beryllium-material using respondents indicated that copper-beryllium alloys were used in their operations.

There is a wide range of manufacturing activities which involve copper-beryllium alloys to some degree. We have classified the operations described in the following sections in terms of how the copper-beryllium alloy is used. In some establishments, more than one category of activity is carried out.

3.3.1 Casting and Forging

There are seven Ontario foundries identified by the Ministry of Industry and Trade as being involved in casting copper-beryllium alloys [28]. All were included in the mail-out questionnaire survey and, of the five that responded, four acknowledged that copper-beryllium castings were among the products they produced. During the project we also identified one foundry (making aluminum and magnesium high-precision castings) which prepared and cast an aluminum alloy containing a very small percentage of beryllium (0.04 to 0.07 percent).* Although qualitatively different, the steps involved in producing ordinary copper-beryllium castings and high-precision aluminum alloy castings are, in fact, quite similar. The stages in the production of speciality aluminum castings are shown in Figure 3-5 as an example of the casting processes.

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[*] This does not imply, of course, that nickel-beryllium is not used in Ontario. It is merely that none of the 133 survey respondents did so.

Sand casting appears to be the technique most often used for the production of copper-beryllium castings and is also the one employed by the company making high-precision aluminum and magnesium castings. Rough casting of copper-beryllium billets, however, is carried out in reusable steel moulds.

The first step in the sand casting process is the making of patterns which duplicate every detail of the item to be cast (for a brief discussion of patternmaking see, for example, Holliday *et al.* [section 3.3.1 of reference 30]). A mould of the pattern is then prepared from adhesive bonded sand. Moulds can be very intricate affairs. Within a mould are channels to allow the molten metal to flow freely to all areas in the mould. Depending on the complexity of the casting, these channels (called runners and risers) can result in a considerable amount of surplus metal being attached to the casting. Figure 3-6a shows a small sand mould ready for casting.

The casting alloy is prepared in a refractory crucible which is often referred to as a ladle. The crucible is charged with the primary metal and/or recycled scrap alloy and heated in a furnace [Figure 3-6b]. When melted, carefully calculated quantities of the alloy's minor ingredients are added in the form of nuggets or pellets of a master alloy — copper-beryllium and aluminum-beryllium master alloys contain four and five percent beryllium, respectively. The molten metal is mixed and a sample of the alloy is taken for quality control analysis by dipping a small sampling ladle into the crucible. There is a possibility

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* Aluminum and magnesium foundries were not included in the mail-out questionnaire survey, so no idea of the number which might use aluminum-beryllium alloys was obtained. But since such alloys are not very common, and are limited to special applications [2], the number may well be very small.

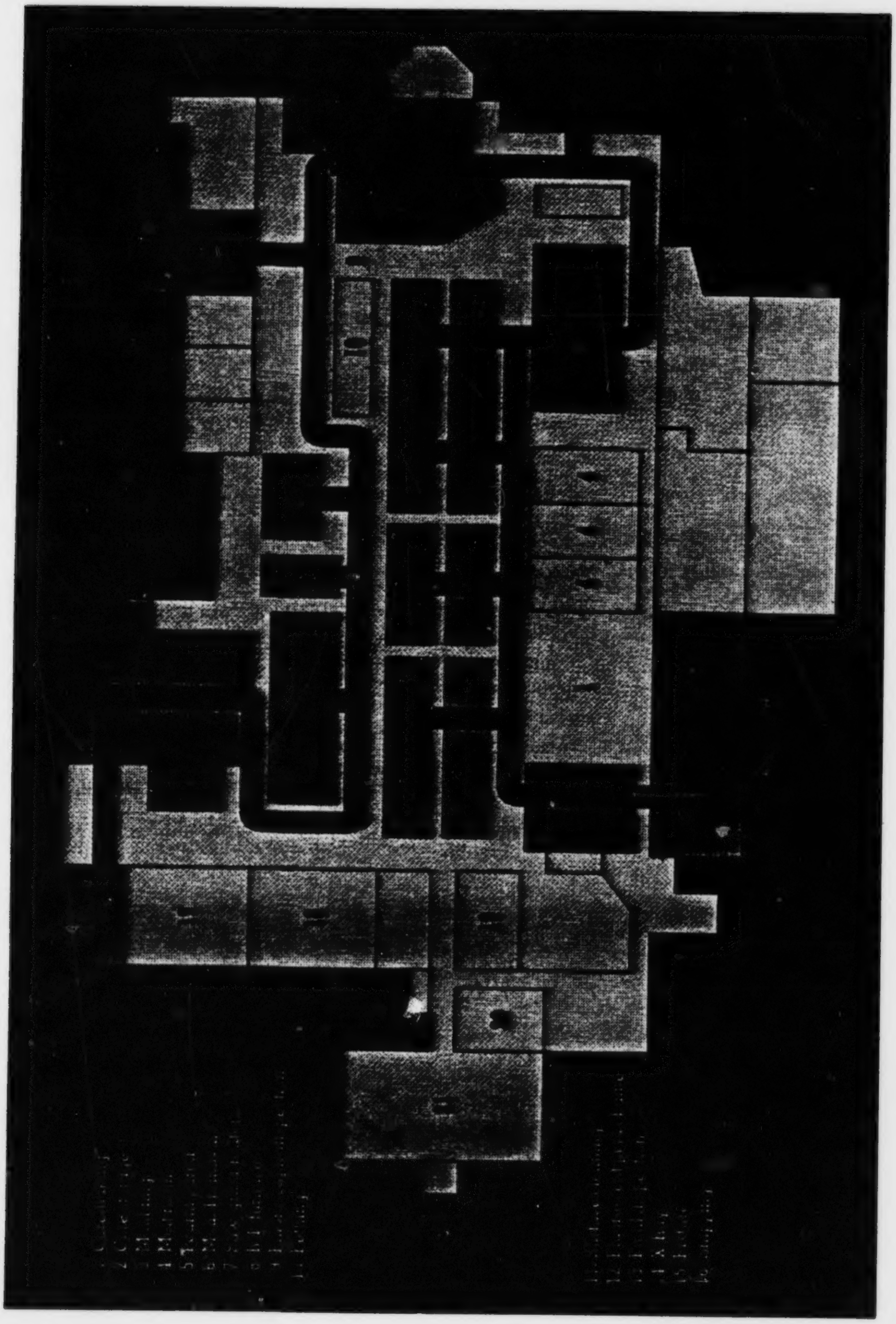


FIGURE 3-5 Stages Involved in the Production of High-Precision Aluminum Alloy Castings [29]

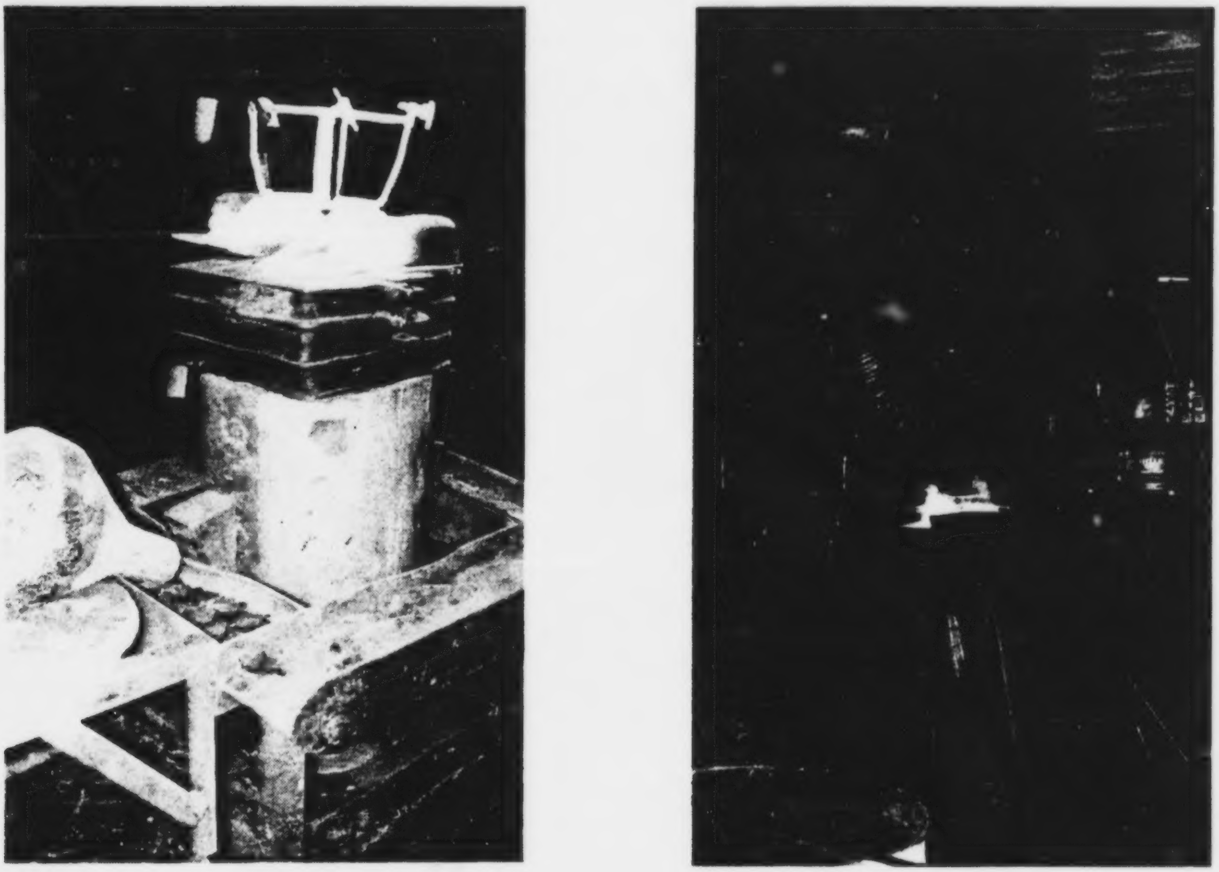
for beryllium vapour to be present in the fumes given off from the molten material and hence the potential for worker exposure during alloy preparation.

The next stage involves taking the crucible of molten alloy to the pouring area and pouring the metal into the mould [Figure 3-6c]. Considerable fumes (mould gases) are generated when the hot metal hits the casting sand. Metal vapour from the molten alloy may become entrained with the mould gases and hence a potential for exposure to beryllium would exist.

After the casting has cooled, the sand is removed (commonly in an enclosed mechanical shaker known as a "wheelabrator"). Runners, risers and extraneous metal are removed from the casting using band saws, routers and grinders. The rough castings are heat treated to relieve stresses set up in the metal during the casting operation. With the exception of some final grinding and sanding, this may be all that is required for simple castings. But with more complex castings and high-precision castings, the final preparation can be quite extensive and could involve additional grinding, sanding and routing, as well as drilling, tapping and polishing. If required, surface cleaning and conditioning are also carried out. (Sulphuric acid, nitric acid and hydrofluoric acid baths were used for this purpose in one foundry visited). Such finishing processes as grinding and sanding can result in the generation of airborne beryllium-alloy dust and are hence potential sources of beryllium exposure.

A casting can be subjected to a variety of quality-control tests (e.g., fluoroscopic inspection, ultrasonic testing, X-ray photography) both during its finishing and when it is a final product. In some cases, such minor defects as small cracks and surface blemishes may be rectified by welding. Fumes from this activity are another potential source of exposure to beryllium vapour.

Some foundries manufacture billets of copper-beryllium. The rough-cast billet is machined to remove the imperfect surface layer. This operation is known as skimming and yields a homogeneous billet of standard dimensions [Figure 3-6d]. Additionally, forging may be carried out to give copper-beryllium particular physical properties. Forging involves heating a billet to red heat and then hammering it [Figure 3-6e]; a process which



a) Mould ready for casting.

b) Electric furnace for melting and preparing alloy (note local exhaust installed at top of furnace).

c) Casting (note local ventilation hood above pouring ladle and protective equipment worn by the workers)

FIGURE 3-6 Examples of Operations Used in Casting and Forging of Copper-Beryllium

d) Skimming a rough cast billet of copper-beryllium.

e) Hydraulically-driven forging hammer.

FIGURE 3-6 (Cont'd)

may be repeated a number of times. The potential for worker exposure to beryllium during skimming and forging would be very small.

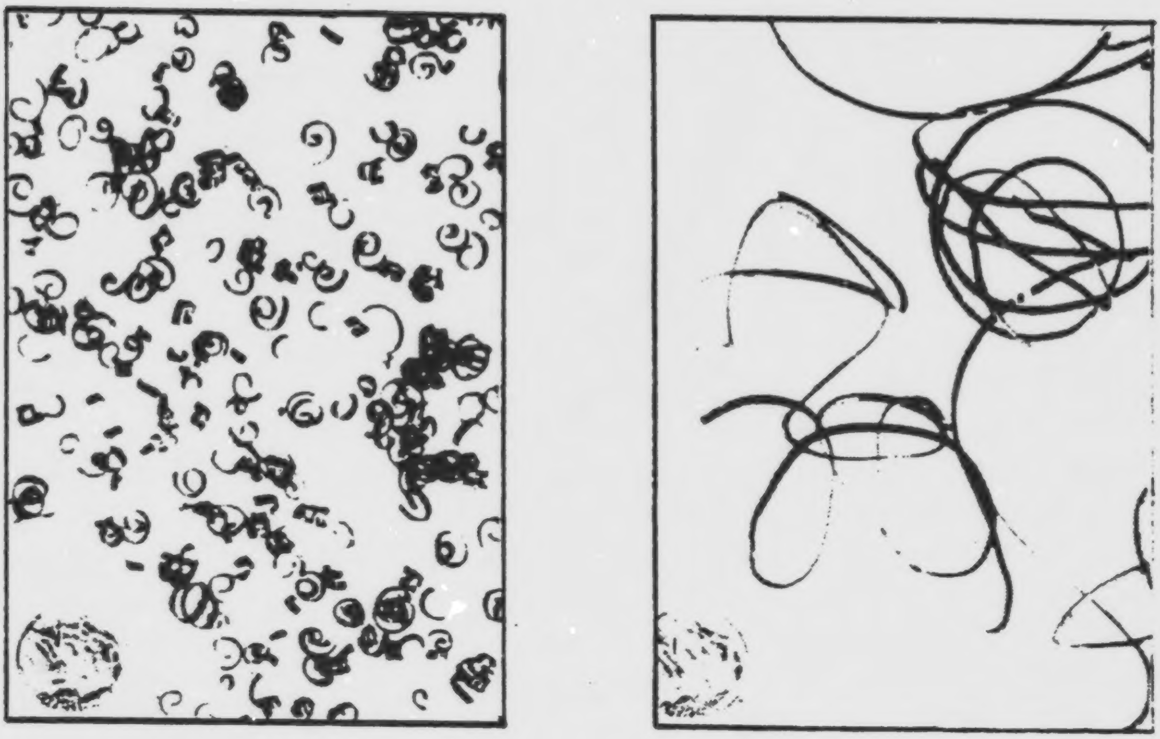
3.3.2 Machine-Shop Operations

Copper-beryllium is a readily machinable material, although care has to be exercised to avoid hardening problems. The use of coolants (chemical emulsions, water soluble oils, and mineral lard oils) is recommended for all machining operations [31]. Although the primary purpose of coolants is to facilitate cutting and the production of a good machined surface, their use also minimizes generation of airborne metal particles. Copper-beryllium can, however, be quite successfully machined "dry" and, indeed, we observed this to be a comparatively common practice.

The quantity of copper-beryllium alloys machined in Ontario is not large in comparison with other non-ferrous alloys like bronze and brass. Nonetheless, the alloys are used in a variety of industries and all types of machine-shop operations are carried out: turning, milling, drilling, tapping, grinding, sanding and polishing. From an occupational-health viewpoint, operations which have the potential for generating airborne particles would be of prime concern. As demonstrated in Figure 3-7, turnings from copper-beryllium tend to be comparatively large with little dust formation. Lathe work, milling, and drilling would therefore appear to offer little chance for worker exposure to beryllium. Grinding and sanding operations generate finer particles and, if carried out "dry", have a greater exposure potential.

Three different types of manufacturing operations are described in the following sections. They are representative of the types of activity in which copper-beryllium is used.

3.3.2.1 Manufacture of moulds for blow- and injection-moulding plastic: Most plastic containers (e.g., dish-washing liquid bottles) are made by a blow-moulding process. Aluminum is the most common material used in such moulds. Copper-beryllium (and/or stainless steel) is used when greater durability is required (polyvinyl chloride, for example, gives off hydrogen chloride during the moulding process and the mould has therefore to be made from corrosion resistant material).



a)

b)

Note: Both examples were generated from a high conductivity copper-beryllium alloy (0.4 to 0.7% Be). Example a) was from a free-machining variety.

FIGURE 3-7 Chips Formed in the Machining of Copper-Beryllium Alloy [32]

A wide variety of solid plastic products is made by injection-moulding techniques. The increasing use of plastics in automobiles (e.g., radiator-fan shrouds, heater box and ducts, radiator grilles, headlight bezels), in particular, has led to a rapidly growing market for injection-moulded plastics and, hence, for the production of injection moulds. These moulds are predominantly steel, but certain sections (e.g., where improved heat conduction is required) may be made from copper-beryllium.

Mould manufacture is a comparatively laborious process. A manager of an establishment making blow moulds, for example, estimated that the process took from 10 to 12 weeks if they started from scratch. Moulds are manufactured by companies specializing in mould making, certain precision machine shops, and by some larger plastics-moulding establishments which have in-house precision machining capabilities. All three types of establishment also repair and refurbish existing moulds.

The mould is designed and a pattern made. The first machining is done using a milling machine equipped with a mechanical or electro-mechanical device which enables the contours of the pattern to be exactly copied. This process results in a roughed-out mould [Figure 3-8a], the interior surfaces of which have to be ground and polished to a smooth finish. This work is often carried out using miniature hand grinders [Figure 3-8b] and hand polishing with strips of emery paper and mineral spirit as a lubricant [Figure 3-8c].

3.3.2.2 Bushing manufacture: In addition to good thermal conductivity, high-strength copper-beryllium alloys have excellent wear characteristics and possess inherently good lubricity [8] — properties which make the material suitable for bushings. There are thousands of applications in which metal bushings are used and their manufacture involves straightforward precision machining. One specific application for which copper-beryllium appears to be favoured is in wing-pick-up bushings for aircraft.* A brief description of how they are manufactured can serve as a typical example of bushing manufacture.

The bushings are machined with slightly oversize dimensions from copper-beryllium bar stock. Because the bearing surface has to have an excellent finish, such bearings are

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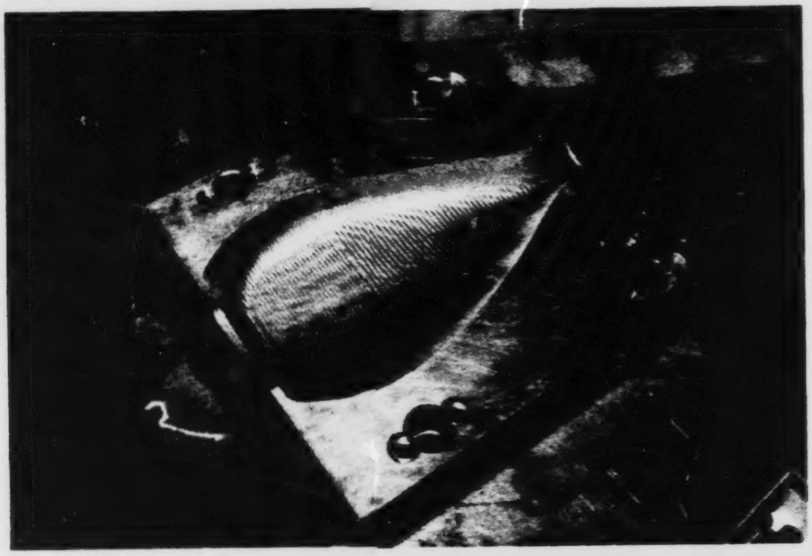
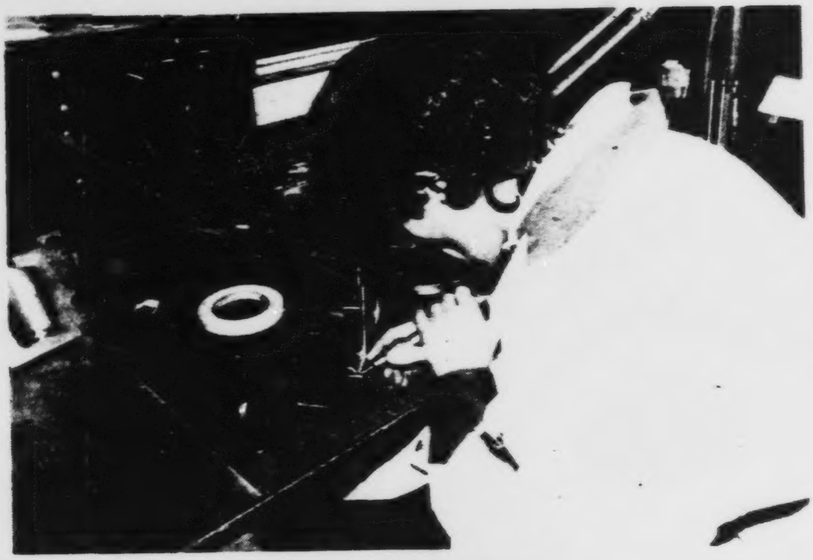
* Wing-pick-up bushings are located in an aircraft's wing strut at points where the wing is attached to the fuselage. In one aircraft, for example, there are 16 bushings for each wing.



a) Half of a Cu/Be blow mould after initial roughing out.



b) Use of a miniature grinder to prepare the interior surface of a mould.

c) Polishing of the blow-mould surface.

FIGURE 3-8 Examples of Stages in Blow-Mould Manufacture

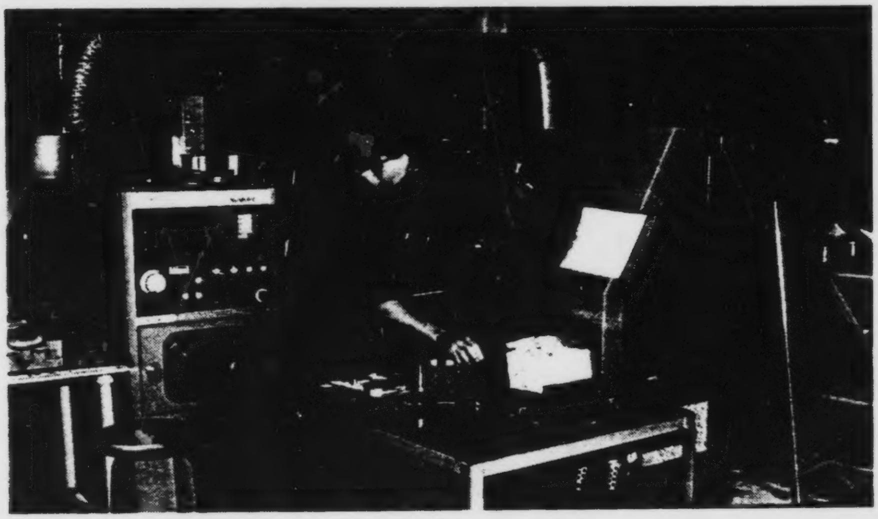
commonly machined under flood-coolant conditions using computer controlled lathes. The bushings are cleaned and degreased, and then chilled in dry ice. The cooled bushing is placed in a jig and pressed into place in the wing strut. The bushing expands on warming thus ensuring a rigid bond with the wing strut. The final operation is to clearance drill the internal diameter of the bushing to its final dimensions. Worker exposure to airborne beryllium would be minimal during these operations.

3.3.2.3 Manufacture of resistance welding electrodes: Resistance welding electrodes need to possess good electrical and heat conductivity, and, for some heavy-duty activities, considerable structural rigidity. These electrodes are made from copper alloys whose properties are the subject of standards specified by the Resistance Welder Manufacturers' Association (RWMA). Two of the four categories of electrode alloys are copper-beryllium alloys (RWMA 3 and RWMA 4). Discussions with industry representatives suggest that no more than about 25 percent of resistance welding electrodes are made from copper-beryllium alloys. The electrodes are either in rod form (the most common type, and used for spot welding [Figure 3-11a]) or disc form (used for seam welding [Figure 3-11b]).

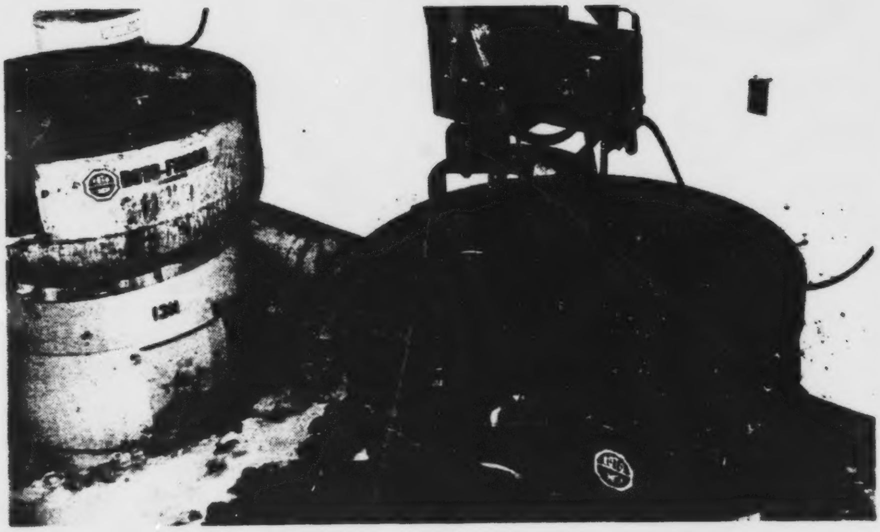
A rod-type electrode has a passage running down its centre to carry cooling water to the tip. Copper-beryllium electrodes are commonly designed to have a detachable copper cap at the tip. It is this cap which comes in contact with the metal being welded. The cap serves two purposes — the life of the (comparatively) expensive copper-beryllium electrode is prolonged (the cap merely being replaced when it wears out) and the production of beryllium-containing fumes is prevented. As we observed during a plant visit, the steps involved in producing such electrodes are simple and few:

- bar stock is cut to length (typically 4" to 8");
- drilling of the central passage is carried out on a turret lathe with an adequate supply of coolant [Figure 3-9a];
- the tip and base of the electrode are machined on an automatic lathe with a flood-coolant system [Figure 3-9b];
- the machined electrode is bent to shape using a hydraulic press; and, finally,
- the completed electrodes are cleaned and polished in rotary tumblers [Figure 3-9c].

a) Turret lathe (note coolant stream, the large size of the turnings, and the bar stock ready for machining).



b) Computer-controlled lathe with flood coolant system (note enclosure of the lathe and the ventilation ducts).



c) Rotary tumblers for polishing finished electrodes.

FIGURE 3-9 Examples of Equipment Used in Manufacture of Resistance Electrodes

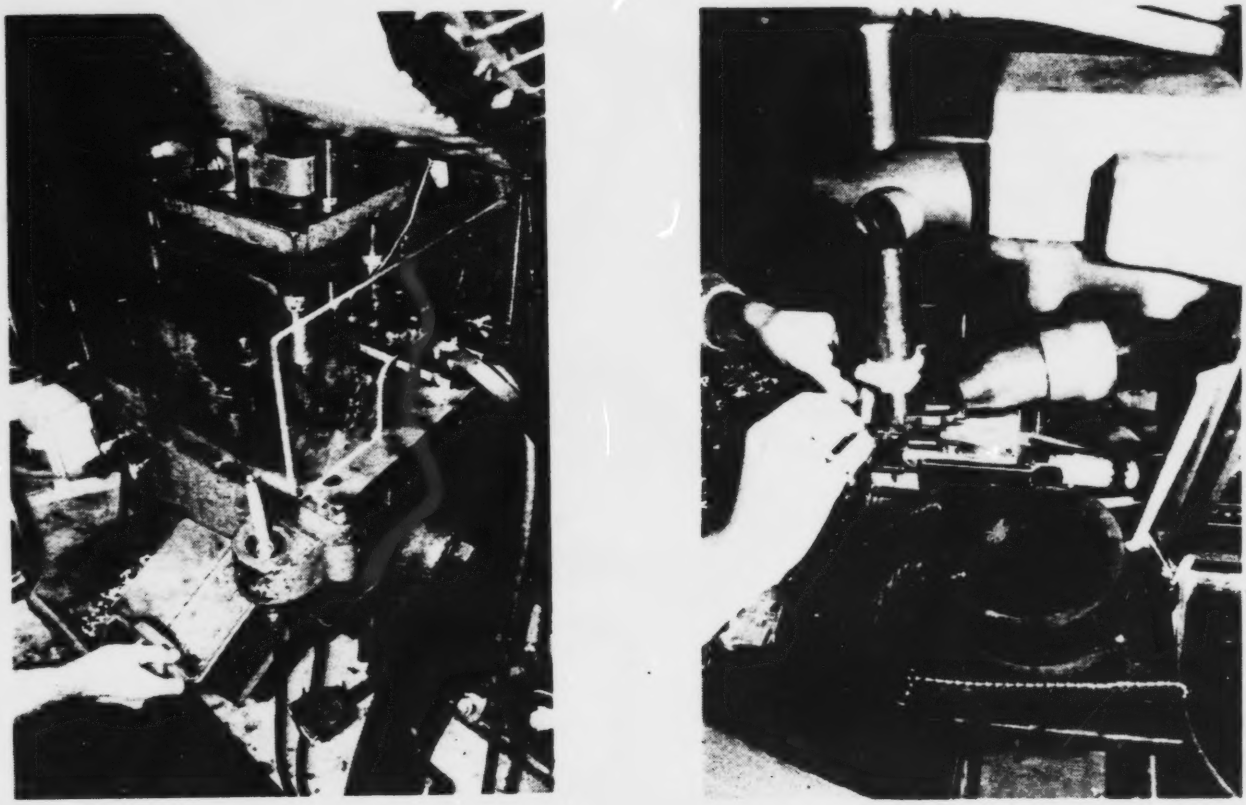
Other types of resistance welding electrodes are machined from castings and forgings rather than from bar stock.

3.3.3 Forming of Parts

The "springiness" and fatigue resistance of tempered copper-beryllium are important characteristics of the alloy. These properties lead to the use of copper-beryllium in corrosion resistant springs and fastenings (high-strength alloys) and in a wide variety of electrical contacts and switchgear (high-conductivity alloys). The manufacture of such items is a high volume operation and is often extensively automated.

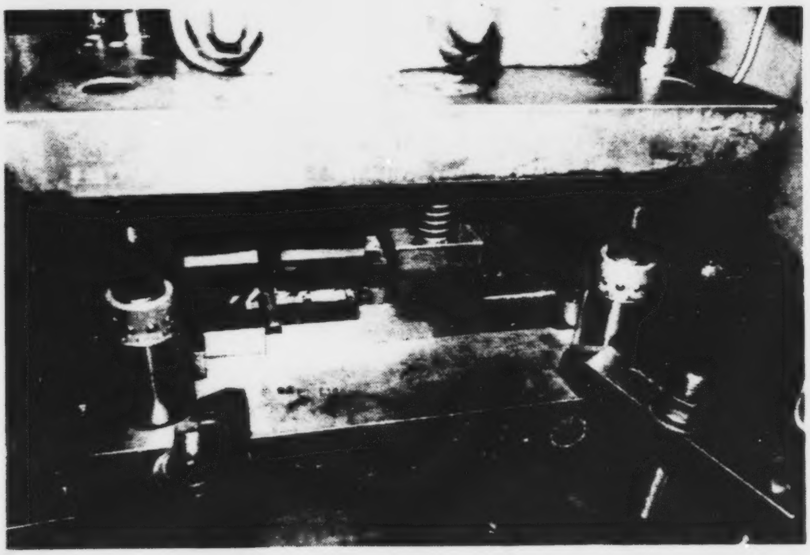
An example of this type of operation was seen at a manufacturing plant visited during the study. A small part of the plant's production involved the manufacture of three different sizes of copper-beryllium contact blades for an electrical switch assembly (not made at the plant) — some 35,000 of the blades being produced every month. Copper-beryllium strip (supplied in the form of 30 to 40 pound coils) is mounted on an "air feeder" which automatically feeds the strip to a blanking press [Figure 3-10a] fitted with a progressive die [Figure 3-10c]. This machine punches a hole, notches the blade, punches a second hole, forms the blade and cuts it off at the correct length; these stampings take place sequentially in four steps as the copper-beryllium strip progresses through the die. The second stage of the process involves the spot welding of a silver-graphite contact on the end of each blade. This process is done manually and local exhaust is provided to remove any fumes which might be generated during the spot welding [Figure 3-10b]. The final stage involves tumbling the completed blades in a soap/water solution to produce a bright finish. After drying, the contact blades are packaged for delivery to the customer. There is a considerable amount of scrap copper-beryllium produced during the stamping operation; this material is sold back to the supplier for recycling. The silver-graphite tip is cut off any reject contact blades and sent for silver reclamation.

The process just described is typical of many stamping operations, although for some electrical contacts the sequence and nature of the individual procedures may be more intricate. Spring-coil manufacture, on the other hand, is a simpler operation. Copper-beryllium wire is wound on a coil-making machine, the coils are cut to length and then tempered to the desired hardness. Even simpler are the slitting and cutting operations



a) Blanking press (Cu/Be strip enters from the right, stamped out part collected in bins)..

b) Spot welding of a silver-graphite contact onto Cu/Be blade (local exhaust 3" away from welding point).



c) Progressive die in which four stamping operation are performed sequentially.

FIGURE 3-10 Examples of Operations Involved in Producing Switch Parts

carried out by suppliers of copper-beryllium strip and wire. None of the processes involved in these forming and cutting operations is likely to result in airborne beryllium. The only hazard mentioned during the telephone interviews and plant visits was the remote possibility of workers cutting themselves on the thin strips of copper-beryllium.

3.3.4 Copper-Beryllium Used as a Tool Component

There are a number of activities in which copper-beryllium alloys, while not being used as a primary material, play an integral part in manufacturing activities. In these secondary uses, workers are handling beryllium-containing material and there could be instances, perhaps during maintenance, in which a potential for beryllium exposure may exist. A couple of examples are discussed by way of illustration.

3.3.4.1 Resistance welding: As already mentioned [Section 3.3.2.3], copper-beryllium electrodes are used in about 25 percent of all resistance welding equipment — particularly that designed for heavy-duty use. The automobile assembly industry is the largest single user of resistance welding equipment in Ontario. The household appliance industry also makes extensive use of resistance welding. In fact, it is likely that any manufacturing activity which necessitates the joining of sheet steel (e.g., metal furniture manufacture) uses resistance welding.*

In automobile manufacture, spot welding is extensively employed on the main assembly line and in sub-assembly areas. Both manually operated spot welding equipment [Figure 3-11a] and robotic equipment [Figure 3-11c] are used to assemble the automobile body. The manual spot welders have replaceable non-beryllium-containing copper tips — these tips are replaced after each shift. Continuous seam welders (which have copper-beryllium disc electrodes) [Figure 3-11b] are used for such applications as gas-tank welding. Maintenance personnel are responsible for fitting, replacing and refurbishing electrodes. The disc electrodes, which become pitted with use, are refaced in the plant's machine shop. Some special electrodes (used on a robot welder at the plant visited) are machined in-house from copper-beryllium bar stock.

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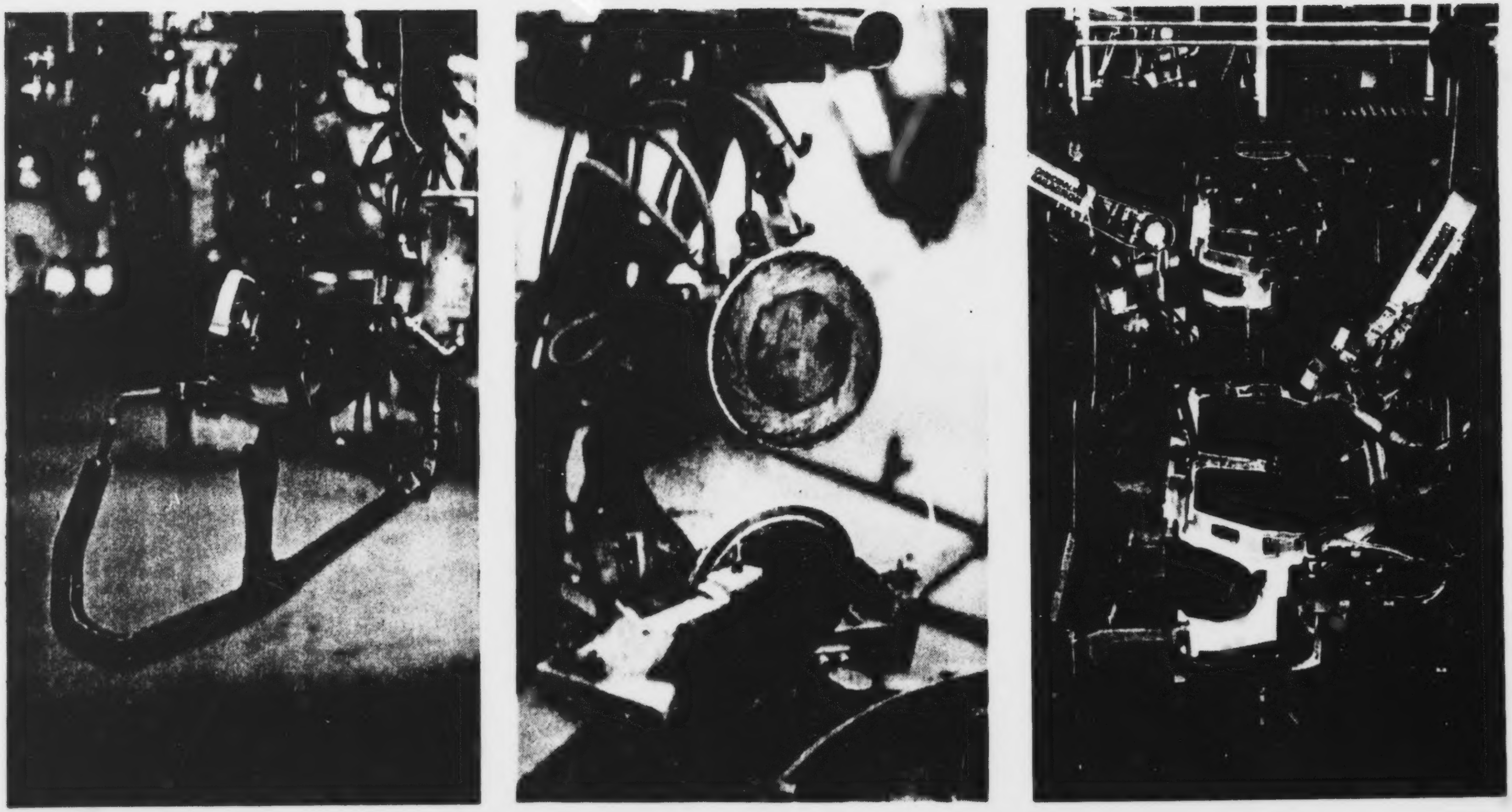
* Our industry survey did not, however, target such manufacturing activity and thus this supposition cannot be confirmed.



a) Hand-held spot welder

b) .Seam welder

c) Robot welders

FIGURE 3-11 Examples of Resistance Welding Equipment Used in the Automobile Industry

Continuous seam welders are also used by household appliance manufacturers. The equipment is, however, somewhat different from that portrayed in Figure 3-11b. It consists of a welding wheel and a flat bar (rather than two welding discs). The wheel and bar are positioned above and below the sheet metal seam being welded, contact is made, current applied and the assembly travels along the seam to form the weld. The electrodes become pitted with use and are refinished by machining and/or grinding.

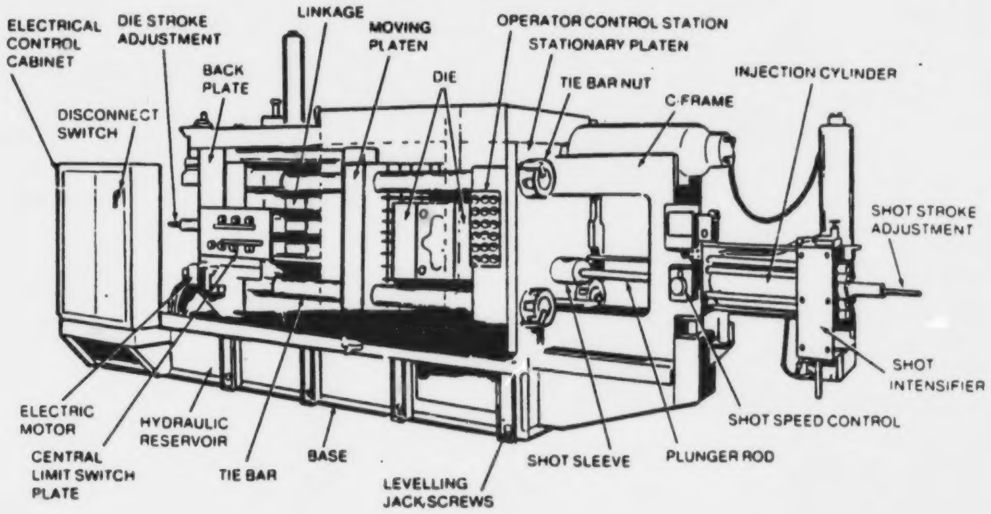
3.3.4.2 Aluminum die casting: Aluminum die casting involves the injection of molten aluminum into a water-cooled steel mould or die. The aluminum part cools and solidifies and is ejected from the die. The process is then repeated — a cycle time of about one minute would be typical. Figure 3-12 gives a general idea of the equipment and sequence of operations used in a cold-chamber die-casting process (cold-chamber machines are used for the die casting of aluminum alloys [33]). The automotive industry is the largest single user of aluminum die castings, typical examples of which are carburetor and alternator parts, transmission casings, and engine components. Other major applications are component parts for: household appliances; various types of machinery; photographic, optical, recording and office equipment; portable tools and electric motors [33].

Although copper-beryllium may occasionally be used as part of a die-casting mould, the principle role of the alloy in aluminum die casting is as a plunger tip in the die-casting machine. Copper-beryllium is used for plunger tips because it possesses good thermal conductivity and hardness, and resists galling in the steel shot sleeve.

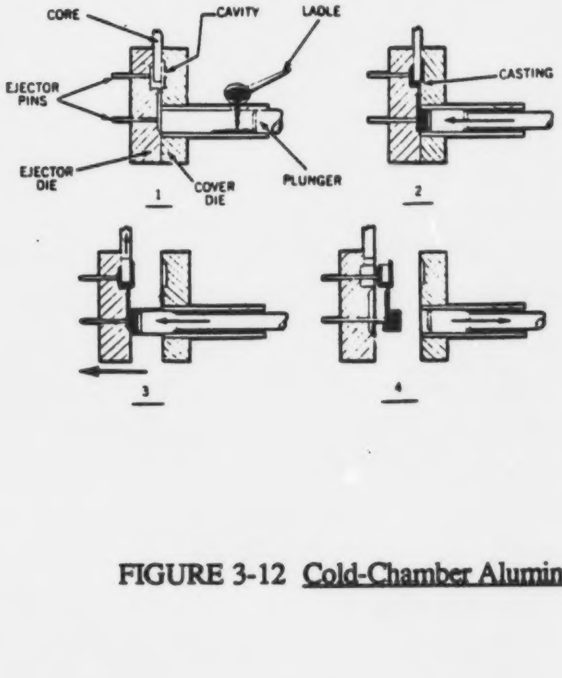
The plunger tip (Figure 3-13a shows some examples) closely fits the inside diameter of the shot sleeve. Repeated die-casting cycles create wear on both the plunger tip and the shot sleeve. Scoring occurs and there is loss of pressure which requires replacement of both the sleeve and the plunger tip. On some occasions, the face of the plunger tip may become chipped (a condition known as "washout") leading to complete loss of pressure and requiring immediate replacement of the tip. Plunger tips and shot sleeves are, on average, replaced about weekly in normal operation.

Both sleeves and tips are refinished so that they may be used again. A worn plunger tip is machined to the next size down and then matched with an appropriately smaller-bore shot sleeve. The machining is carried out on a lathe [Figures 3-13b & c] and normally a

OVERALL VIEW OF EQUIPMENT


ELECTRICAL CONTROL CABINET
DIE STROKE ADJUSTMENT
LINKAGE
MOVING PLATEN
OPERATOR CONTROL STATION
STATIONARY PLATEN
BACK PLATE
DIE
TIE BAR NUT
INJECTION CYLINDER
C-FRAME
DISCONNECT SWITCH
SHOT STROKE ADJUSTMENT
SHOT INTENSIFIER
ELECTRIC MOTOR
HYDRAULIC RESERVOIR
SHOT SPEED CONTROL
CENTRAL LIMIT SWITCH PLATE
BASE
SHOT SLEEVE
PLUNGER ROD
TIE BAR
LEVELLING JACKSCREWS

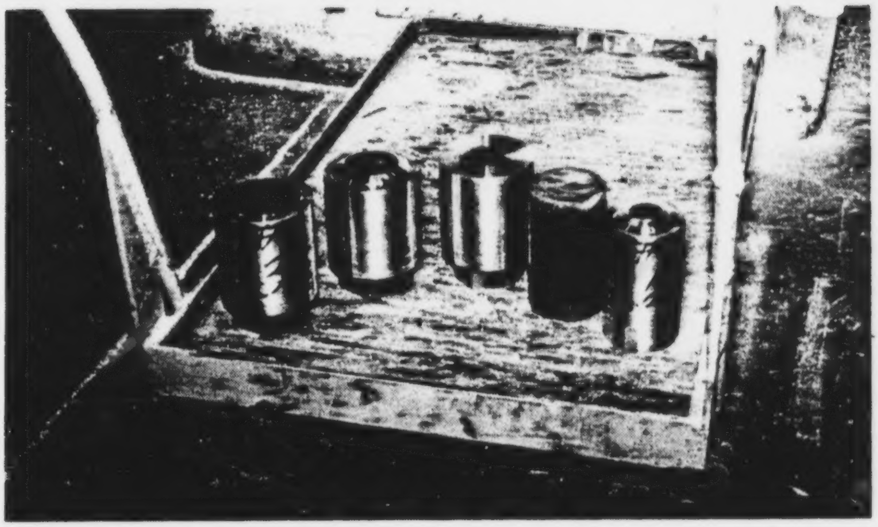
DETAILS OF OPERATING SEQUENCE


CORE
CAVITY
LADLE
EJECTOR PINS
CASTING
EJECTOR DIE
COVER DIE
PLUNGER
1
2
3
4

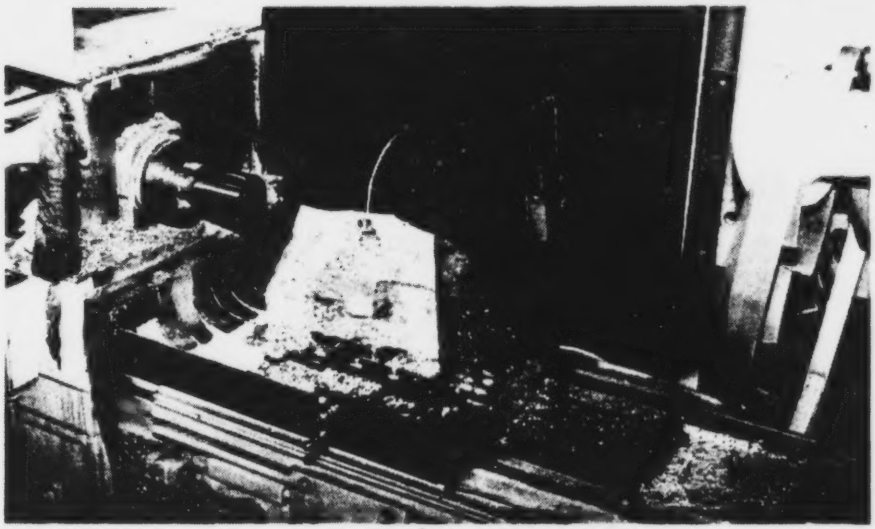
The operating sequence of the Cold Chamber die casting process is as follows:

1. Die is closed and molten metal is ladled into the cold chamber;
2. Plunger pushes molten metal into the die cavity. The metal is held under pressure until it solidifies;
3. Die opens and plunger advances to ensure casting stays in ejector die. Cores, if any, retract;
4. Ejector pins push casting out of ejector die and plunger returns to original position.

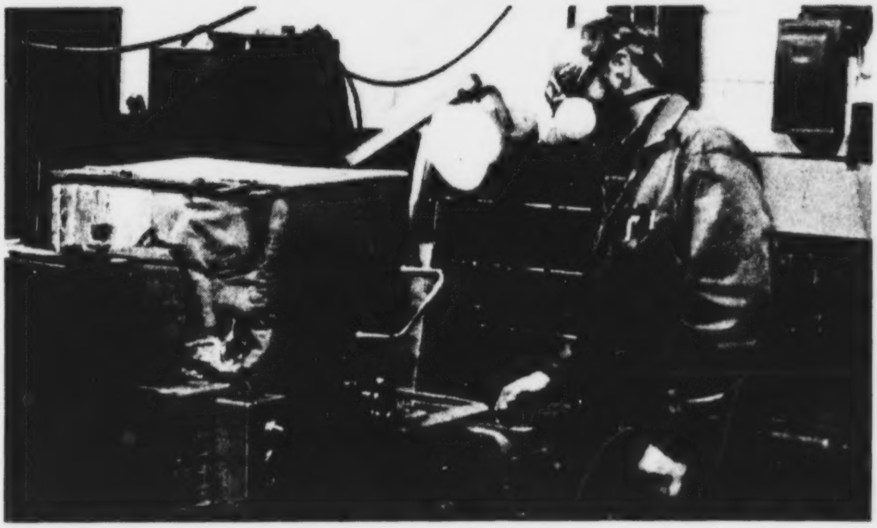
FIGURE 3-12 Cold-Chamber Aluminum Die Casting [33]



a) Die-casting plunger tips; the one second from the right is an example of a tip prior to refinishing.



b) Plunger tip mounted in lathe chuck (machining cover in raised position).



c) Machining of plunger tip (note: machining cover in place).

FIGURE 3-13 Machining of Die-Casting Plunger Tips

coolant is used — we did, however, observe occasions where the machining appeared to be carried out "dry". A final surface polishing may be carried out, usually while the tip is still being turned on the lathe, using emery cloth. It is these refurbishing operations in which there may be a potential for beryllium exposure, but such exposure is likely to be insignificant if proper work-shop practices (e.g., avoidance of "dry" machining and sanding) are adopted.

3.3.5 Miscellaneous Uses of Copper-Beryllium

In the interest of completeness, it is worth concluding this review of the use of copper-beryllium in Ontario with mention of some secondary activities which involve the alloy. None of these activities result in generation of airborne material and hence beryllium exposure would be non-existent.

3.3.5.1 Handling and assembly: There is a wide variety of companies which purchase copper-beryllium components from stamping houses and spring manufacturers and merely assemble the components into a final product. Electrical connectors and contact blades find use in the production of such diverse items as electronic cable assemblies, electrical switchgear, and military electro/optical surveillance equipment. In some cases the company involved in the assembly work will electroplate the connectors before final assembly, in other cases a company may purchase the component already plated, but often the copper-beryllium component is used in an unplated form. Copper-beryllium springs are also found in a multiplicity of equipment: household locks, communications devices, laser controls, public telephone coin-box locks, and detent springs in brake assemblies for heavy duty trucks were some of the examples provided by respondents to the questionnaire survey. In most cases the springs are purchased already cut to size and ready to insert into the equipment being assembled.

3.3.5.2 Scrap reclamation: Such activities as machining of copper-beryllium and stamping operations generate a considerable amount of scrap metal which has to be removed from the manufacturing establishment. We were told during the study that the supplier of copper-beryllium will purchase scrap alloy for recycling, but only in quantities of a thousand pounds or more — the amount paid is considerably higher than that paid for ordinary scrap copper. While this arrangement is satisfactory for companies which generate large quantities of copper-beryllium scrap, it is of little use for the smaller users of the material. These companies usually sell their scrap to scrap metal dealers but get paid only the price for scrap copper. We are not certain what happens to the beryllium-containing scrap in these cases. One company which deals in non-ferrous scrap metal and operates an electro-winning process to recover copper from copper-containing scrap metal, stated that to their knowledge they did not receive copper-beryllium: "No one would sell it to us, anyway, because we'd only pay normal scrap copper prices", was their comment.

3.4 SUMMARY

Although the quantities of beryllium, beryllia, and beryllium alloys used in Ontario are not large (certainly in comparison with other non-ferrous metals and alumina), the materials are widely dispersed within Ontario industry and are used for a diversity of applications. The occupational exposure potential, through not necessarily the actual exposure, varies from high (e.g., operations involving pure beryllium in a powder form) to the non-existent (e.g., assembly of parts containing fractions of a percent of beryllium).

3.4.1 Beryllium Metal

Beryllium metal is used in the manufacture of certain specialized equipment for aerospace and military applications (e.g., gyroscopes used in inertial guidance systems, parts for a speciality camera). This manufacture demands high-precision machining of beryllium (often to within a few ten thousandths of an inch) using miniature lathes, drills, grinders and even sand-blasting equipment. All machining equipment is enclosed and provided with local ventilation.

Beryllium is used in the brazing of zircaloy spacers to fuel tubes which make up the fuel bundles used in Candu reactors. The process is essentially a three stage operation: vacuum deposition of beryllium metal onto the spacers, tack welding spacers on the zircaloy fuel tubes, and radio-frequency induction brazing of the tacked spacers to the fuel tubes.* Another nuclear application is the use of a beryllium neutron reflector in a small research reactor manufactured in Ontario. The shield, which surrounds the reactor core, is machined under contract by a United States supplier.

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* All this activity takes place before the zircaloy tubes are charged with the uranium dioxide fuel.

3.4.2 Beryllia

Beryllia is a ceramic material used as a substrate for hybrid micro-electronic circuits which require exceptional heat dissipation characteristics. (Most such circuitry employs alumina as the substrate, a material with a much lower thermal conductivity than beryllia.) Three operations in microcircuit manufacture could result in the generation of airborne substrate materials (beryllia or alumina): laser scribing, laser trimming of resistors, and separation of individual microcircuits. It is uncertain whether any companies in Ontario currently manufacture microcircuits on beryllia substrates, but one company which responded to the mail-out questionnaire indicated they might be doing so in the future. Two companies were, however, identified as using beryllia in some of their assembly work. One produced a hybrid circuit mounted on a beryllia base and the other used beryllia washers to isolate a power supply.

3.4.3 Beryllium Alloys

By far the most common beryllium containing materials used in Ontario are beryllium alloys — predominantly copper-beryllium. Their production, application and use embrace a variety of different Ontario industries.

Both copper-beryllium and aluminum-beryllium alloys are produced in Ontario. The alloys are used to produce a multiplicity of castings and forgings. Potential for occupational exposure to beryllium during such operations exists during the melting of the alloys, the pouring of the castings, and removal of extraneous metal from the casting.

Copper-beryllium alloys are machined to produce a number of products, of which moulds for injection- and blow-moulding of plastic products, bushings (e.g., wing-pick-up bushings in aircraft), and resistance welding electrodes are the most clearly identifiable categories. Copper-beryllium strip is used in stamping operations to form electrical connectors and contacts, and numerous kinds of fastenings. Copper-beryllium wire is formed into all sizes and grades of springs. The primary source of airborne beryllium-containing material in these activities would be machine-shop operations involving "dry" working of the alloy (particularly grinding and sanding). Forming and stamping operations are unlikely to result in airborne material.

Copper-beryllium is used in "secondary" operations (i.e., operations in which the alloy is not directly converted into other products) as a tool component. Resistance welding, probably the most widespread use in this category, is extensively employed in the manufacture of automobiles and large household appliances. The welding electrodes are in many instances made of copper-beryllium alloy. Exposure potential is slight and would mostly be confined to maintenance of the electrodes (e.g., refacing of welding wheels). Copper-beryllium plays a small but critical role in aluminum die casting. The plunger tip in the die-casting equipment is made of copper-beryllium. The tip, which forces the molten metal into the die, becomes worn in use. Periodically, the tips have to be refurbished by machining and grinding.

Finally, there are a variety of assembly operations in which copper-beryllium components are used. Typical examples are electronic connector assemblies, electrical switchgear, spring operated assemblies, and brake assemblies for heavy duty trucks. Exposure potential is non-existent because there are no processes in the assembly of such articles which result in destruction of copper-beryllium.

4. EXPOSURE CONTROL

The measures taken to control worker exposure to beryllium and beryllium-containing materials in Ontario industry range from the comprehensive and stringent to the non-existent. By and large, the extent of the control measures adopted in a particular industry is a reflection of how hazardous the use of such materials is perceived by that industry to be. An idea of this hazard perception may be gained from the discussion of measures taken in various industrial settings presented in the following sections. And, to add dimension to this discussion, the chapter concludes with estimates of the number of workers exposed.

4.1 BERYLLIUM USERS

Few establishments in Ontario carry out operations in which there is a potential for the generation of airborne beryllium metal. Four were identified in this study and there are probably no more than half a dozen. The use of beryllium in these operations is specialized and no substitutes for the metal are available. Exposure control by substitution is not, therefore, a practical control measure.

The measures adopted by all four establishments are similar — controlled-access areas dedicated only to the handling of beryllium, local ventilation at all potential sources of airborne beryllium, a designated workforce, and regular monitoring. Two of the four companies carry out precision machining of beryllium metal, while the other two employ beryllium in the brazing of spacers on Candu fuel tubes.

4.1.1 Precision Machining

For both companies, the machining of beryllium is a minor aspect of their manufacturing activities. Nonetheless, the value of the beryllium products produced appears sufficient to justify a dedicated, controlled area for the machinery operations.

4.1.1.1 Engineering controls: The area where machining of beryllium occurs is separated from other work areas within the plant. The controlled beryllium-area has a dedicated ventilation system which maintains the controlled area at a negative pressure with respect to the rest of the plant. Machining equipment is provided with local exhausts (see, for example, Figures 3-1 and 4-1a), as are inspection and equipment-maintenance locations [Figures 3-1a, 3-1f]. Both the local-exhaust systems and the general area ventilation are exhausted to the atmosphere through high-efficiency dust-collection and filtration systems [Figure 4-1b].

4.1.1.2 Work practice controls: Only designated employees are permitted in controlled beryllium-areas. These employees comprise both the few machinists who spend their entire workday in the controlled area and such personnel as maintenance workers, industrial hygienists, and design engineers who have occasion to enter the area from time to time.

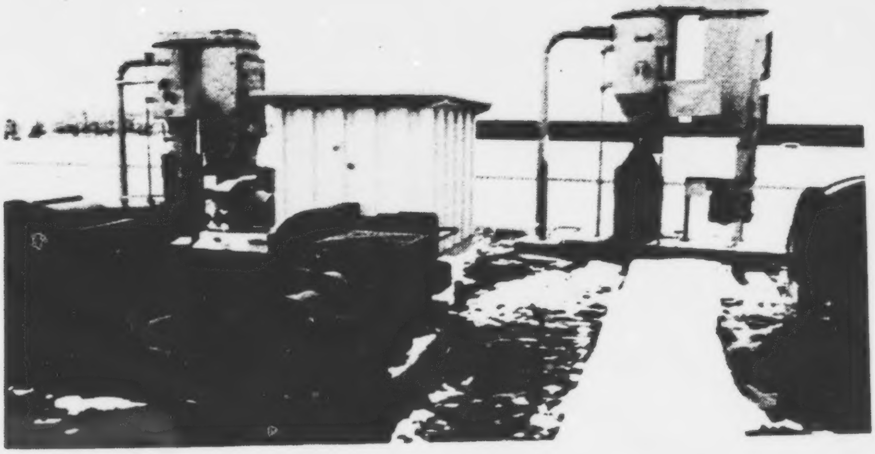
Everyone in the beryllium area is required to wear coveralls over their normal clothes and to wear overshoes or specially designated work shoes. Neither the coveralls nor the overshoes or work shoes are permitted to leave the controlled area. A laundry facility is provided within the area for washing the coveralls [Figure 4-1c]. No item is allowed to leave the controlled area without having its surfaces cleaned to remove any loose beryllium which might be present. All these precautions are designed to prevent beryllium being "tracked" into the remainder of the plant.

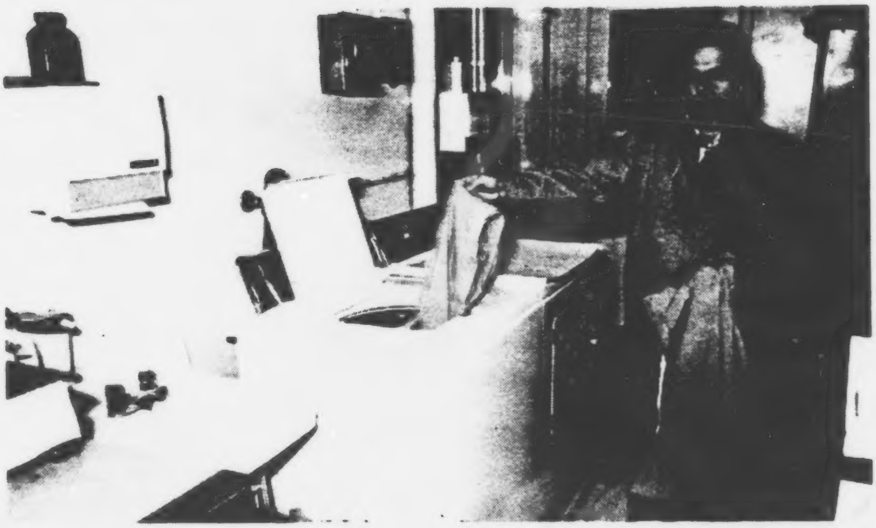
Regular "housekeeping" procedures are in place to ensure that buildup of beryllium dust does not occur on equipment and working surfaces. Eating and smoking are prohibited in the beryllium area and all persons are required to wash their hands before leaving the area.

Particle respirators are worn for newly-introduced machining operations until exposure monitoring shows that the operator's exposure is below guideline levels. But for some limited operations (e.g., where dry grinding of beryllium is unavoidable), operators wear respirators at all times as a precaution, even though monitoring shows that exposures are generally below the company's internal guideline levels. When the ventilation system dust collectors and filters are changed, the workers carrying out the operation wear full protective clothing and air-supplied respirators.

a) Sand blasting unit with additional manual exhaust for bench clean-up (note coveralls worn by worker).

b Ventilation exhaust filters.





c) Laundry within beryllium-controlled area (note, coveralls never leave the controlled area).

FIGURE 4-1 Examples of Engineering and Work-Practice Controls for Machining of Beryllium

4.1.1.3 Monitoring: One of the companies carries out regular monitoring for airborne beryllium, on a spot-check basis, several times a week. The measurements are area samples obtained using a high-volume sampler (a typical sampling time would be 30 minutes at 200 L/min). The regular area samples are occasionally confirmed by personal monitoring. The company operates an "in-house limit" of 0.5 $\mu g/m^3$ for airborne beryllium; levels above this value would trigger an investigation as to the cause. We were told that area samples were rarely above this level and the majority were considerably below. No compilations of personal exposure levels were made available, but it is of interest to note that personal exposure levels (expressed as a geometric mean of all samples) reported for a similarly equipped beryllium machining facility in Israel [Table 4-1] were more than two orders of magnitude below 0.5 $\mu g/m^3$.

In addition to atmospheric monitoring, the company takes regular "swipe" samples from horizontal surfaces in the beryllium area. The company's "action level" for these surface samples is 2 $\mu g/ft^2$ (~20 $\mu g/m^2$). The purpose is to prevent buildup of contamination within the work area.

Both companies require their designated beryllium workers to undergo yearly medical examinations at company expense. The tests include chest X–rays and lung function tests, as well as urinalysis and blood analysis.

4.1.2 Candu Fuel Rod Operations

As mentioned in Chapter 3 [Section 3.1.2], the two companies manufacturing Candu fuel rods employ slightly different processes for brazing the zircaloy spacers onto fuel tubes. Exposure control measures adopted by each company differ in certain details, although the overall approach is similar. To recapitulate from the previous chapter, the three stages involved in the process are vacuum deposition of beryllium on the zircaloy substrate [Section 3.1.2.1], tack welding of spacers onto the fuel tube [Section 3.1.2.2], and final brazing of the spacers onto the tubes [Section 3.1.2.3].

4.1.2.1 Engineering controls: Like the facilities in which beryllium metal is machined, the vacuum-deposition areas are separated from the other work areas in the plants and are provided with independent area ventilation systems. A negative pressure is

TABLE 4-1 Atmospheric Monitoring Results Reported from a Beryllium-Handling Facility in Israel [34]

Monitoring Period	Personal Samples		Area Samples	
	#	Concentration*	#	Concentration*
June 1985	20	0.0017 μg/m^3	20	0.0021 μg/m^3
December 1985	25	0.0034 μg/m^3	29	0.0015 μg/m^3

# number of samples analyzed

* expressed as a geometric mean of all the samples

Note: These data were obtained by collecting air samples on a cellulose acetate filter (0.8 μm pore size) for six hours at an air flow of 2 L/min.

maintained in these areas with respect to the remainder of the facility. The areas where the tack and braze operations are carried out, while being separate from the remainder of the plant operations, do not have dedicated ventilation systems. Local exhaust is, however, provided to glove-box operations and to hoods above the tack welding equipment and this exhaust is part of the dedicated ventilation system. Exhausts from the vacuum pumps used to evacuate the beryllium deposition chambers and the brazing units are also vented into the dedicated ventilation system. Air from the area-ventilation and local-exhaust systems is exhausted to the atmosphere through high-efficiency filtration equipment.

4.1.2.2 Work-practice controls: The operations are carried out by designated beryllium workers (a workforce of about 30 in each company). Both companies have training manuals for beryllium workers (one company has also developed a training video) and both run training sessions for new workers.

The few employees assigned to beryllium coating operations must wear a complete outfit of protective clothing (lab coats, gloves, and rubber boots or overshoes or special shoes at one company; coveralls and designated footwear at the other company). None of this clothing or footwear is allowed to leave the beryllium-controlled area and the protective garments are washed in laundry facilities located within the area. At one company, workers in the beryllium-coating area must wear particle respirators at all times; at the other company, respirators are required only when the vacuum deposition chambers are being loaded or unloaded, and when the chambers undergo cleaning and maintenance (once every one or two months). Personnel regularly employed in beryllium-coating areas must shower at the end of each shift.

Workers in the tack and braze areas wear laboratory coats. All beryllium area workers are required to wash their hands before leaving the facility. Eating, drinking and smoking within the controlled-beryllium area are prohibited.

Careful "housekeeping" procedures are in force at both companies. To prevent tracking of beryllium out of the controlled-beryllium area, floors are wet mopped daily and the work stations are cleaned daily at one company and "at least weekly" at the other. Horizontal surfaces are damp wiped monthly, or more often if "swipe tests" show high levels of contamination.

4.1.2.3 Monitoring: One of the companies has an integrated area-monitoring system with 17 sampling points throughout the controlled area (7 points in the beryllium coating area and 10 points in the tack and braze areas; an air flow of ~20 L/min through each sample filter is provided). The sample filters from each monitoring point are changed daily and are analyzed for beryllium. The results are averaged for each sampling point monthly, and these monthly averages are posted quarterly on workplace bulletin boards. (The fact that daily monitoring data are available enables early corrective action to be taken if an increase in airborne beryllium levels is observed at a particular location.) The company also occasionally carries out personal monitoring as a check on the area monitoring system. The other company carries out daily area monitoring for airborne beryllium in the beryllium-coating area (using medium volume samplers with an air flow of 35 to 40 L/min) and weekly personal monitoring of workers in the same area. Monitoring of airborne beryllium (both personal and area samples) in the other controlled-beryllium areas is carried out on a monthly basis. The monitoring results are posted in the beryllium facility. As can be seen from the data in Table 4-2, the airborne levels of beryllium within the controlled-beryllium area are similar for both companies.

In addition to the monitoring of airborne beryllium levels, the two companies regularly monitor surface beryllium contamination using "swipe tests". The monitoring is performed to prevent unseen buildup of beryllium dust; the monitoring frequency depends upon the degree of surface contamination expected — weekly in the beryllium-coating area and fortnightly for tack and braze areas. Both companies have similar "action levels" for the swipe tests: 400 $\mu g/m^2$ for the beryllium-coating areas and 270 $\mu g/m^2$ and 200 $\mu g/m^2$ for the other areas.

All designated beryllium workers undergo yearly medical examinations which include chest X-rays. In addition, one company carries out urine analysis for beryllium on a quarterly basis.

4.2 BERYLLIA USERS

Only two out of 133 questionnaire-survey respondents reported using beryllia in their operations and in both companies the beryllia is only used in assembly. One of these companies, a hybrid microcircuit manufacturer, was contemplating future manufacture of

TABLE 4-2 Examples of Beryllium Monitoring Results at Two Facilities Fabricating Candu Fuel Rods*

Sampling Location	Company 'A'	Company 'B'
BERYLLIUM COATING AREA		
Personal (TWA)	0.4 to 0.6 μg/m^3	§up to 2 μg/m^3
General area (TWA)	¶	0.1 to 0.2 μg/m^3
At mouth of vacuum deposition chamber when unloading (short-term peak)	—	<1 to 6 μg/m^3
TACK AND BRAZE AREAS		
Personal (TWA)	n.d. to 0.4 μg/m^3	<0.1 μg/m^3
Area (TWA)	¶	<0.1 μg/m^3

* These data were supplied by the companies as being representative of levels encountered in their facilities.

§ Workers in this area wear respirators.

¶ One year's monitoring at all sampling sites (expressed as monthly averages for each individual site) yielded: 0/117 above 2 μg/m^3; 1/117 above 1 μg/m^3; and 116/117 below 1 μg/m^3.

TWA Exposure measured as a time-weighted average.

n.d. Not detected

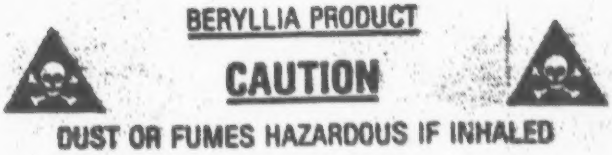
microcircuits on beryllia substrates. As this company already manufactures one product which is assembled on a beryllia base, much of the equipment and workplace procedures needed for full-scale manufacture of beryllia microcircuits are already in place.

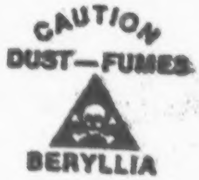
4.2.1 Engineering Controls

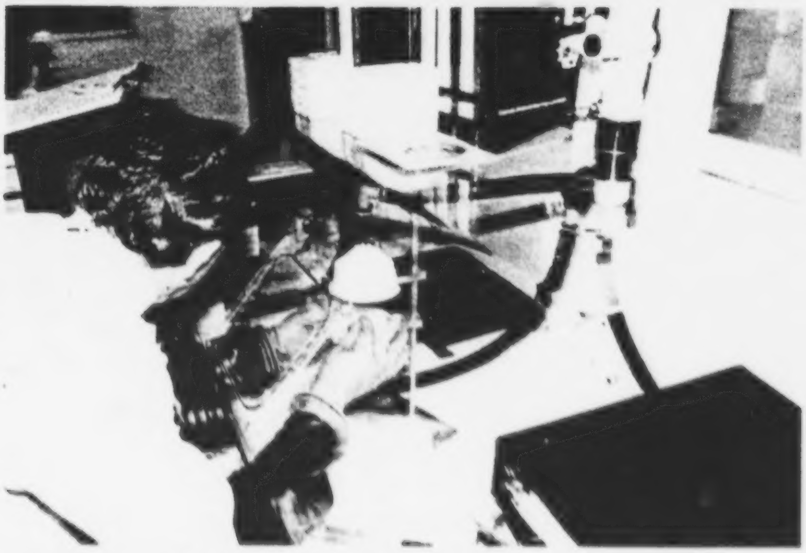
The overall approach to handling beryllia is one of enclosure with ventilation. An example is the glove-box facility shown in Figure 4-2a, a facility used to unpack and inspect beryllia substrates. Of particular note is the local ventilation within the glove box provided at the point where the inspection is carried out. Laser scribing machines (whether for use with alumina or beryllia) are provided with an exhaust mounted close to the laser head [Figure 4-2b]. This exhaust is necessary to remove the considerable amount of substrate dust generated during scribing. A laser scriber is operated with the cover closed and the scribing is computer controlled. The only chance of beryllium exposure would occur when loading and unloading the scriber, and then only if dust which had escaped the local exhaust was disturbed. Laser trimmers can be equipped similarly to laser scribers (as is shown in Figure 3-4a) in order to prevent generated fumes from entering the work atmosphere.

4.2.2 Work-Practice Controls

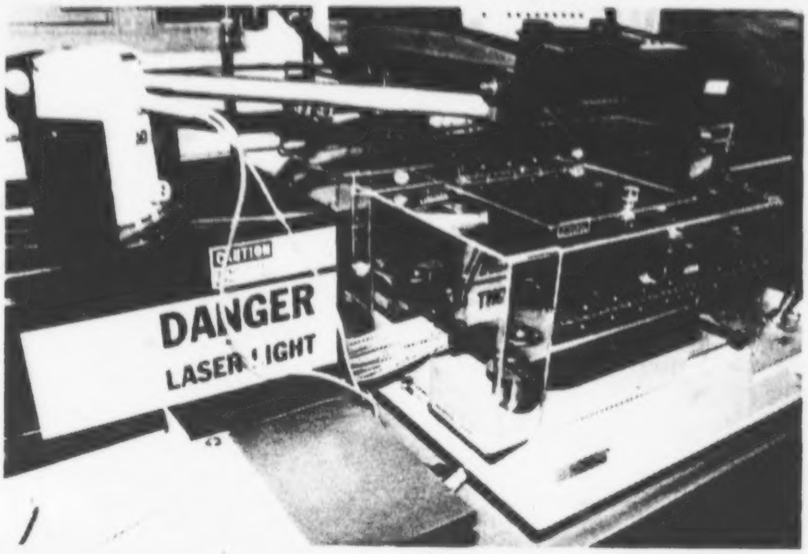
Probably the most important work-practice control is the recognition that it is beryllia which is being used, rather than the visually indistinguishable and less hazardous alumina. It is thus important to clearly identify the beryllia-containing products within a microcircuit manufacturing facility. At the plant visited, the following labels (in "day-glo" red) are affixed to each beryllia product at every stage of the manufacturing process:


BERYLLIA PRODUCT
CAUTION
DUST OR FUMES HAZARDOUS IF INHALED



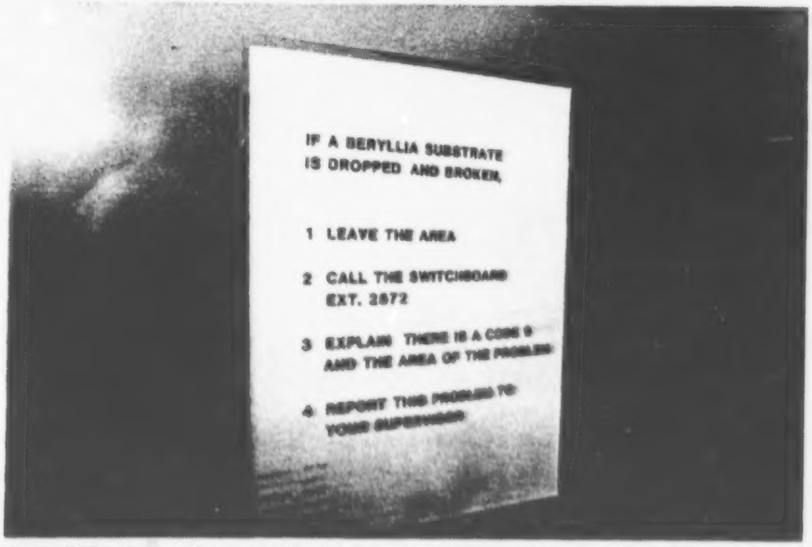


a) Local exhaust at inspection site within glove box for handling beryllia substrates.



b) Local exhaust at the head of a laser scriber.

c) Emergency instructions (these notices were posted in a number of locations within the facility).



IF A BERYLLIA SUBSTRATE
IS DROPPED AND BROKEN,

1 LEAVE THE AREA

2 CALL THE SWITCHBOARD
EXT. 2872

3 EXPLAIN THERE IS A CODE 9
AND THE AREA OF THE PROBLEM

4 REPORT THIS PROBLEM TO
YOUR SUPERVISOR

FIGURE 4-2 Examples of Engineering and Work-Practice Controls in a Beryllia-Handling Facility

There is also a clearly defined emergency procedure for dealing with beryllia substrates which are dropped and broken. The procedure is announced by clear notices posted throughout the manufacturing area [Figure 4-2c]. A specially trained team is used to clean up the debris. The larger pieces are collected and "bagged" in polyethylene, smaller pieces and dust particles are vacuumed up using a portable vacuum cleaner equipped with a high efficiency filter on its exhaust. The clean-up team members wear particle respirators.

4.2.3 Monitoring

Because the company visited only carries out assembly operations involving beryllia, no monitoring for beryllia is conducted. The data presented in Table 4-3, however, do give some idea of the magnitude of exposure which might be expected during the manufacture of hybrid microcircuits on beryllia substrates. These data were obtained by the major supplier of beryllia under simulated work conditions, rather than being measurements conducted during the actual manufacture of microcircuits on beryllia substrates. As expected, it is the laser scribing operation which appears to result in the highest (short-term) exposure limits. Exposure predominantly occurs when the scribed substrates are removed from the laser unit. The levels measured (ranging from non-detectable to 1.5 μg Be/m^3) appear to indicate that the laser equipment can be used for beryllia without modification.

4.3 BERYLLIUM ALLOY USERS

In contrast to the quite specific control measures taken by users of beryllium metal and beryllia, the controls adopted by users of beryllium alloys tend to be the normal good workplace practices without being specific for beryllium-containing material. Indeed, an information videotape, *Beryllium Alloys: Safe Handling* [36], produced by the largest North American supplier of beryllium alloys implies that if the normal industrial hygiene precautions used in handling such metals as stainless steel and nickel are applied to beryllium alloys, occupational exposure levels will be considerably below 2 μg Be/m^3.

TABLE 4-3 Examples of Airborne Beryllium Levels from Handling Beryllia in Typical Microcircuit Production Applications*

Activity	Beryllium Levels	Observations
LASER SCRIBING		
Background samples	0.1 to 0.2 μg/m^3	The average level was 0.15 μg/m^3. Samples taken ~150 cm from laser scriber during the automatic scribing of substrates.
Breathing-zone samples	0.2 to 1.5 μg/m^3	The average level was 0.8 μg/m^3. It was stated that these figures should be considered peak levels, as the samples were taken while the scribed substrates were being unloaded from the laser scriber.
LASER TRIMMING		
Various samples	n.d. to 0.3 μg/m^3	A number of samples were taken at various points surrounding a laser trimming operation. Only 2 samples showed detectable beryllium (0.04 and 0.3 μg/m^3), both were obtained from a point on the trimming table about 30 cm from the laser head.
SNAPPING SCORED SUBSTRATES		
Background samples	0.03 and 0.13 μg/m^3	Two samples were taken at a point ~150 cm from the workbench; one before the snapping operation and one after 986 parts had been snapped.
Breathing-zone samples	0.01 to 0.24 μg/m^3	Three samples were taken at the worker's breathing zone at various times during the hand snapping operation.

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* These data were compiled from information presented by Foley and Rees [25] and Powers [35]. Sampling was conducted during simulated production operations and utilized a high volume air sampler (~250 L/min) with a 9 cm diameter filter. Breathing-zone samples entailed holding the sampler in the approximate area of the operator's breathing zone and sampling for two to three minute periods; background samples were taken over a 10-minute period.

4.3.1 Casting and Forging

Beryllium alloys formed only a small part of the business conducted by the foundries responding to our industry survey. Except in a couple of specific instances, none of the foundries took special precautions when processing beryllium alloys. However, the exposure control measures generally employed in foundries to reduce exposure to fumes, silica, metal dusts, and so on can also be effective in reducing beryllium exposure.

Exhaust ventilation is provided at the furnaces used to prepare the alloy [Figure 3-6b], with the ladle used to pour the molten metal into the mould [Figure 3-6c], and in the pouring area. Local exhaust ventilation is usually, but not always, in evidence at the casting finishing stations where cutting, grinding and other similar operations are carried out.

It is quite common for workers to wear particle respirators when pouring castings (as may be seen in Figure 3-6c) and, in fact, in some establishments such respiratory protection is required. It is also common practice for workers to wear dust masks while grinding castings during the finishing processes.

One foundry contacted required each beryllium-containing casting to be tagged with a label — THIS CASTING CONTAINS BERYLLIUM — to identify such castings as they move through the finishing processes. This same company also repaired small surface blemishes (voids and cracks) by welding. When welding is carried out on a beryllium-containing casting, the worker is required to wear an air-supplied respirator. (We were told that this measure was recommended to the company some 10 years ago by a Ministry of Labour inspector.)

None of the foundries routinely monitor for airborne beryllium. One company showed us the results of monitoring surveys carried out by the Ministry of Labour. The results of both personal and area samples had all been recorded as 0.001 mg Be/m^3 or <0.001 mg Be/m^3 (TWA). There were no indications in the Ministry's reports of detection limits, but from the "constancy" of the numbers reported (i.e., 0.001 or <0.001) we suspect that the detection limits must have been close to 1 μg Be/m^3.

4.3.2 Machine-Shop Operations Involving Copper-Beryllium

When respondents were asked during follow-up telephone interviews [Appendix II] about exposure-control measures taken during machining of copper-beryllium, the answer was invariably that "wet" conditions were used. Such statements as: "We use an automatic lathe with a flood-coolant system — it's totally enclosed", "all our lathe work is done wet", and "we never do dry grinding", were typical of the replies received. A couple of respondents (out of the 12 to 15 who counted machining as part of their operations) mentioned exhaust hoods above lathes, and a few more mentioned local ventilation provided at grinding stations. While most stated that only "wet" grinding was carried out, one or two respondents suggested that if "dry" grinding were done, workers would wear a mask.

This state of affairs is really what would have been expected. Information provided by the suppliers of copper-beryllium recommend the use of cutting fluids and coolants while, at the same time, stressing the easy machineability of the alloy [31,37]. Because of the strong precipitation-hardening characteristics of copper-beryllium alloys (Wikle and Harlan state that such hardening can occur through prolonged heating at 290°C and will begin almost immediately at 370°C [37]) the use of coolants is obviously the preferred practice and will result in higher machining speeds, prolonged tool life, and a better surface finish. It is also felt that the use of sufficient coolant will reduce airborne metal particles. Nonetheless, occasions were observed during plant visits in which copper-beryllium was being machined under "dry" conditions.

Only one respondent mentioned carrying out regular monitoring of airborne beryllium in their machine shop; an event that was done once a year by an outside consultant. We were assured that levels were always below 2μg Be/m^3. A few of the other respondents reported that the Ministry of Labour had carried out monitoring at their plant and had found levels acceptable. "The Ministry came by 12 years ago and gave us a clean bill of health", was one remark.

An idea of the exposure levels which may be expected from machining copper-beryllium can be gained from the investigations carried out by Senn at the Lawrence Livermore Laboratory [19]. He studied the levels generated by milling and sawing copper-beryllium alloys (predominantly one containing 1.8% beryllium, but also one containing 0.5%) under simulated machine-shop conditions. From the data presented in Table 4-4, it can be seen that breathing zone levels would normally be expected to be in the range of non-detectable to 1 μg Be/m^3 for milling operations. It is interesting, however, that the data do not appear to show the expected reduction in exposure levels with "wet" machining. Senn had no ready explanation for this, except to note that there was considerable individual variation of beryllium concentrations in the triplicate samples. However, the one result (>7 μg Be/m^3) obtained under deliberately bad milling conditions (dry cutting with a blunt milling tool leading to rapid work hardening of the alloy) perhaps underlines the advisability of ensuring good machine-shop practices.

The effect of cutting fluids was more clearly seen when Senn investigated band-sawing of cylindrical billets of copper-beryllium [19]. The breathing-zone concentrations of beryllium were found to be about 1 μg Be/m^3 when the sawing was carried out under dry conditions, but were less than 0.1 μg Be/m^3 during wet cutting.

If the data obtained by Senn can be considered as representative of normal work-shop experience, then machining of copper-beryllium would appear to generate exposure levels similar to those encountered in the strictly controlled environment of pure beryllium metal handling (see Sections 4.1.1.3 and 4.1.2.3).

4.3.3 Stamping, Slitting and Cutting Operations

All respondents interviewed in the telephone follow-up to the questionnaire were unanimous in their opinion that stamping, slitting or cutting of copper-beryllium strip and wire generates virtually no airborne beryllium. None of the companies, therefore, had any exposure controls associated with these operations. A few respondents, however, mentioned that workers wore gloves to protect against cuts from thin strips of the alloy. And one respondent said that workers were required to wear cotton gloves to prevent sweat stains on the copper-beryllium.

Stamping, slitting and cutting are not the only activities involving copper-beryllium carried out in some establishments. One company, for example, spot-welded a silver/graphite contact onto copper-beryllium. Local ventilation is provided at the welding

TABLE 4-4 Average Breathing Area Concentrations of Beryllium in Total Dust Samples Taken During Milling Operations*

Type of Milling Tool	Special Conditions	Beryllium Concentration ($\mu g/m^3$)
End mill (HSS)	dry cut	0.9
Fly cutter (CT)	thick dry cut (0.025")	0.4
Fly cutter (CT)	thin dry cut (0.010")	<0.05
Shell mill (HSS)	dry cut	0.4
Shell mill (HSS)	wet cut	0.4
Shell mill (HSS)	dry cut	0.3
Shell mill (HSS)	wet cut	0.9
Shell mill (HSS)	¶dull tool, dry cut; excessive heat & noise	7.4
Shell mill (HSS)	dry cut	2.0

HSS high speed steel

CT carbide tipped

* From information presented by Senn [19]. These data were obtained under simulated working conditions, using copper-beryllium containing 1.8% beryllium, on an automatic milling machine. A static sampler was used with sample points located about 1.5 m above ground level and 0.3 to 0.6 m from the cutting head – triplicate samples were taken. "Normal" area ventilation of about 12 air changes per hour was provided during the experiments.

¶ Deliberately abnormal conditions. Dull tool caused rapid work hardening of copper-beryllium because of heat generated. This, in turn led to further blunting of the tool and heat buildup, causing early termination of the experiment.

point [Figure 3-10b] to remove any fumes which might be generated. The company reported that the Industrial Accident Prevention Association (IAPA) monitored for airborne beryllium in 1985, but no detectable levels were found. Another company carried out a low temperature welding process on stamped copper-beryllium parts; workers involved in the welding wear respirators and the welding stations are provided with local exhaust ventilation.

4.3.4 Copper-Beryllium Used as a Tool Component

It is not the actual use of copper-beryllium in resistance welding, aluminum die casting, and plastic blow-moulding which presents a potential for exposure to beryllium, but rather the maintenance practices associated with these uses. The machine-shop practices and exposure control measures employed in refacing resistance welding electrodes, refurbishing die-casting plunger tips, and repairing blow moulds are similar to those utilized in the machine-shop manufacture of copper-beryllium products — practices already described in Section 4.3.2. The exposure levels would also be expected to be similar, but time-weighted average exposures would likely be lower for the maintenance activities because it is likely that not as much continuous machining would be done.

One respondent involved in blow moulding of plastics mentioned that it had been their practice to repair cracked copper-beryllium moulds by welding them, but the company had discontinued this practice on the advice of its industrial hygienist. Though not a common practice, one machinist involved in the refurbishing of die-casting plunger tips wore a particle respirator while carrying out the machining [Figure 3-13c]. This is not a company requirement, but the worker had read that "beryllium was poisonous" and he "wasn't going to take any chances"; he had requested a respirator and the company had supplied him with one.

4.4 NUMBERS OF WORKERS EXPOSED

Our estimates of the number of workers exposed to beryllium-containing materials in Ontario industries are presented in Table 4-5. These data are based on respondents' answers to the mail-out questionnaire [Section III.3.4, Appendix III], information obtained during follow-up telephone interviews, and on what we observed during plant visits. As

TABLE 4-5 Estimates of the Number of Workers Exposed to Beryllium in Ontario*

	Potential Exposure to Airborne Be		Handling Be-Containing Materials	
Manufacturing Activity	Regularly[¶]	Intermittently[§]	Regularly[¶]	Intermittently[§]
BERYLLIUM METAL				
Precision machining	6 to 8	150 to 200[α]	- -	- -
Nuclear applications	60	- -	- -	4
BERYLLIA				
Microcircuits	?	?	?	15 to 30
BERYLLIUM ALLOYS				
Casting and forging	120 to 180	15 to 25	- -	- -
Fabrication/machining	150 to 300	20 to 40	?	- -
Stamping and cutting	25 to 50	- -	300 to 600	50 to 100
Aluminum die casting	60 to 90	- -	200 to 300	- -
Resistance welding	~200[β]	?	~2000[γ]	?
Plastic moulding	3 to 15	6 to 30	- -	4 to 20
Handling and assembly	- -	- -	150 to 300	100 to 200
TOTALS[δ]	600 to 900	200 to 300	2700 to 3200	200 to 400

* Estimated from mail-out questionnaire responses [Appendix III], information provided during follow-up telephone interviews, and from what was observed during plant visits.

¶ Once or twice per week, or more often

§ less than once a week to as little as 5 days in 3 years

-- essentially none, other than those already identified

? insufficient information to make estimate

α workers permitted access to beryllium-controlled area, but not regularly in the area (maintenance personnel, industrial hygienists, design engineers, etc.)

β machinists involved in either manufacturing or refacing resistance-welding electrodes, or in refurbishing die-casting plunger tips

γ maintenance workers and electricians

δ rounded to the nearest 100

discussed in the earlier sections of this chapter, there are a number of industrial activities involving beryllium-containing material that do not result in the generation of airborne beryllium. In Table 4-5, therefore, we have differentiated between workers who solely handle beryllium-containing materials and those who are also potentially exposed to airborne beryllium. This latter group comprises about one quarter of all workers who handle beryllium-containing materials in Ontario.

The overall estimate of 3600 to 4800 Ontario workers who would deal in some way with beryllium-containing material is in fair agreement with the estimate, presented in Appendix III, of 4000 to 5700 made using Ontario manufacturing labour force data (a derivation which employs a different approach to the one used in Table 4-5). The estimate of 900 to 1200 Ontario workers who are potentially exposed to airborne beryllium compares quite favourably with the estimate of 30,000 workers in the United States who would have potential exposure to dust or fumes containing beryllium [12];* particularly when it is remembered that there is no primary production of beryllium and its compounds in Canada, and that virtually all of the beryllium alloys used in Canada are imported from the United States.

4.5 SUMMARY

By and large, the exposure-control measures adopted in establishments handling beryllium-containing materials reflect the companies' perceptions of the hazards of beryllium exposure within their particular manufacturing operations. These measures range from the comprehensive and stringent to the non-existent. Operations which solely involve assembly of beryllium-metal or beryllium-alloy components pose virtually no exposure hazard and hence no exposure-control measures are considered necessary by the companies involved in this activity.

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* This comparison is based on the facts that the United States manufacturing sector is about 10 times larger than the one in Canada and that Ontario contributes about 50 percent of Canada's manufacturing activity. This would lead to an estimate of 1500 Ontario workers based on the United States figures (i.e., 30,000 x 1/10 x 0.5).

4.5.1 Beryllium Metal Users

Although the processes used in the two activities involving beryllium metal in Ontario, namely high precision machining and brazing spacers on the fuel sheaths for Candu nuclear reactors, are different, the exposure-control approaches adopted by the companies are similar.

The handling of beryllium takes place in restricted-access areas equipped with dedicated area ventilation systems (i.e., the systems are not connected to the ventilation for other areas in the facilities). Much of the beryllium handling equipment is enclosed and provided with local exhaust ventilation. Access to the beryllium-handling areas is via changing rooms and is limited to designated employees. Coveralls, designated footwear and, where necessary, particle respirators are worn by persons in the restricted beryllium areas. Nothing is permitted to leave the controlled area without first being decontaminated; this precaution prevents "tracking" of beryllium into other areas of the plant. Laundry facilities for washing the coveralls are located within the controlled areas. Eating, smoking and drinking within controlled areas are prohibited.

There is regular monitoring of atmospheric beryllium levels in all the plants. Monitoring of surface contamination ("swipe tests") is also done on a regular basis. Results of the monitoring are periodically published in the workplaces. Exposure levels are generally below 0.5 μg Be/m^3 in areas where machining of beryllium is carried out, and below 2 μg Be/m^3 in areas where vacuum deposition of the metal is undertaken.

There appear to be six to eight workers employed daily in machining beryllium in Ontario, and a further 150 to 200 workers who have access to the machining areas on an intermittent basis. There are about 60 workers who are exposed daily to beryllium in activities connected with the brazing of spacers onto Candu fuel sheaths; some four to six of these are employed in the vacuum-deposition areas. All designated beryllium workers undergo yearly medical examinations, with particular attention being paid to lung condition.

4.5.2 Beryllia Users

Although no company was identified in the industry survey as currently manufacturing hybrid microcircuits on beryllia substrates, one company indicated that they may do so in the future. The control of exposure to airborne beryllium during manufacture of microcircuits on beryllia substrates depends on enclosure of equipment and local exhaust ventilation, as well as on an awareness among the workforce that it is toxic beryllia which is being handled rather than the visually similar and much more common non-toxic alumina. From the few data regarding atmospheric beryllium levels generated by processes involved in producing microcircuits (breathing-zone levels ranging from non-detectable to 1.5 μg Be/m^3) it appears that equipment (e.g., laser scribers and trimmers) used for the manufacture of microcircuits on alumina may be also used for beryllia with little or no modification.

One company identified in the industry survey produces electronic devices assembled on a beryllia base. The company employs simple work-practice controls, prime among which is the precautionary labelling of each beryllia device at every stage of the manufacturing process. The company has a very thorough and clearly identified clean-up procedure to be followed if beryllia substrates or circuits are dropped and broken: area evacuation, clean-up by a specially trained team wearing respirators and using a specially exhausted vacuum cleaner, and careful bagging of the broken pieces for disposal.

There are possibly some 15 to 30 workers in Ontario engaged in electronic assembly work involving beryllia substrates. This work, however, is not likely to be conducted on a full-time basis. We do not know whether there are any Ontario companies which manufacture hybrid microcircuits on beryllium substrates — none were identified in the industry survey.

4.5.3 Beryllium Alloy Users

In contrast to the practices employed in operations involving beryllium metal or beryllia, there are few control measures used to specifically reduce beryllium exposure in operations involving beryllium alloys. Normal metal-handling and machine-shop practices are usually considered adequate.

In foundries, local exhaust ventilation is provided at the alloy-melting crucibles, in the area where castings are being poured, and at work stations where excess metal is removed from the casting by sawing, grinding, and routing. One company required workers to wear supplied-air respirators when carrying out welding repair of minor surface defects in castings. No clear idea of beryllium exposure levels encountered in foundry operations was obtained, but representatives of the industry indicated that they thought exposure was generally below 1 μg Be/m^3. Perhaps some 150 to 200 workers are involved in casting and forging operations dealing with beryllium alloys.

There is general agreement that machining copper-beryllium under "wet" conditions (i.e., with the use of adequate quantities of coolants and cutting fluids) prevents appreciable exposure to airborne beryllium. There was also a feeling that "dry" grinding of the alloy presented the greatest potential for excessive exposure. Some companies claimed that all grinding at their establishments was carried out under wet conditions; others provided local exhaust ventilation for their grinding operations. Both "wet" and "dry" machining and grinding of copper-beryllium were observed during plant visits. Very little idea was gained of beryllium exposure levels encountered in these machine-shop operations. Some data are available from experiments conducted under simulated machine-shop conditions which indicate that breathing-zone concentrations would generally be below 1 μg Be/m^3 for both "dry" and "wet" machining, but that under adverse circumstances (e.g., use of blunt cutting tools and lack of coolant) considerably higher levels could be encountered. There are probably some 400 to 700 Ontario workers involved in machining copper-beryllium alloys.

A number of activities (resistance welding, aluminum die casting, plastic injection- and blow-moulding) involve the use of copper-beryllium as a tool component. This use does not directly lead to worker exposure to airborne beryllium, but the attendant maintenance activities (refacing resistance-welding electrodes, refurbishing die-casting plunger tips, and repair of moulds) can require machining of the copper-beryllium components. There are also, in Ontario, a number of operations which solely involve assembly of copper-beryllium components. There will be no exposure to atmospheric beryllium in these activities. Stamping and similar operations involving copper-beryllium (e.g., fabrication of electrical connectors, production of copper-beryllium springs) is another activity which would not result in atmospheric beryllium exposure. The number of workers who might be involved with merely handling copper-beryllium products (as opposed to workers who handle and machine or cast the alloy) would be in the range of 2900 to 3600. The majority are employed in the automobile industry.

5. PERCEPTIONS AND OPINIONS

Numerous comments, observations and opinions regarding beryllium exposure in the workplace were received during the study. The points raised, often subjective in nature, are an integral part of the occupational-health "picture". Taken as a whole, the comments and opinions expressed by both management and labour representatives left us with the impression that the use of beryllium and its compounds presented no particular or pressing problems — at least not under the conditions extant in the companies contacted.

5.1 PERCEPTIONS OF THE HAZARDS OF BERYLLIUM EXPOSURE

The manner in which the exposure hazard is viewed ranges from one of extreme caution to one almost verging on indifference. By and large, this range in perception coincides with the apparent range in hazard potential.

5.1.1 Beryllium Metal Users

There was good awareness of the potential hazards associated with handling pure beryllium among both management and workers. Perhaps the daily reminder of having to enter a restricted area and having to don special clothing heightened and reinforced the awareness. One did not get the impression that the procedures were considered unnecessary or burdensome. A designated beryllium worker told us:

> "It's always in the back of your mind that beryllium might be harmful. But I've been at it nine years and have no complaints."

He did, however, go on to comment about the attitudes of some of the other workers in the plant:

> "Some of the guys are afraid to come into the beryllium area because they think beryllium is so dangerous."

In some ways, the situation is similar to that encountered in facilities handling radioactive materials — radiation, like respirable beryllium dust, cannot be seen, smelt or tasted. Indeed, two of the establishments which handle pure beryllium also handle radioactive material.

5.1.2 Beryllia Users

Although we did not encounter any company which was engaged in the manufacture of microcircuits on beryllia substrates, we did receive a fairly clear indication that the microelectronics industry considered the handling of beryllia to be quite a hazardous undertaking and many companies did not appear to be particularly keen to use the material. One respondent from a microelectronics company (which used copper-beryllium, but not beryllia) told us:

> "Many people confuse beryllia, which is a very poisonous substance, with beryllium-copper, which is inert" (our emphasis).

We are uncertain as to the reasons behind the apparent antipathy towards beryllia in the microelectronics industry. It may be that companies do not want to bother with the extra precautions needed for handling the compound. It was pointed out to us that workers used for the routine production of microcircuits are not necessarily the most highly skilled, and it might be difficult to instill in them the need for more careful handling of beryllia compared with the normal practices used for the much less toxic and much more familiar alumina. One electronics engineer voiced the opinion that the use of beryllia substrates could be rendered unnecessary in many cases if careful thermal analysis of circuit layout were carried out during the circuit-design phase.

5.1.3 Beryllium Alloy Users

It was noticeable in responses to the mail-out questionnaire that a number of respondents had indicated the use of "beryllium" in their operations. Follow-up interviews showed, however, that it was copper-beryllium that was being used. Indeed, during plant visits we found that "beryllium" was a commonly used term for copper-beryllium. This terminology perhaps indicates an awareness that copper-beryllium is "different" from other alloys the plants might be using. It is not, however, possible to say whether this "differentiation" is made on the basis of potential health hazards or on the alloy's physical properties.

In general, there is no strong concern about the hazards of handling beryllium alloys and the following comments were typical of the many we received:

> "We're a small user (of copper-beryllium) and are not aware of any problem with beryllium" [a foundry manager],
>
> "there's no perceived hazard with plunger tips" [an aluminum die-caster)], and
>
> "there's no hazard machining copper-beryllium" [a machinist].

But one foundry manager viewed things differently:

> "I've been told that one over-exposure to beryllium is enough to give you problems 15 years later. Our company doctor thinks it (beryllium exposure) is the number one hazard in the foundry."

And a machinist at an aluminum die-casting operation, who wore a particle respirator when machining plunger tips (see Figure 3-13c), explained:

> "A while back, ____________________ (a supplier of die-casting plunger tips) began putting these labels on their packing boxes which said you shouldn't dry grind the tips. And soon after I started this job (refurbishing plunger tips) I noticed I was getting a red rash on the inside of my elbows. I figured that dust from sanding was getting up the sleeves of my coveralls and giving me a rash. So I put two and two together and talked to the (Health & Safety) Committee. They gave me this mask and I've been wearing it ever since."*

While there is clearly a difference in how the potential hazard of beryllium alloys is perceived, there is probably consensus that the materials can be handled safely.

5.2 CONTROL: REGULATORY AND OTHERWISE

It should be pointed out that most of the comments gathered during the study were received before December 1986 when the Ontario Government's *Regulation Respecting Control of Exposure to Biological or Chemical Agents* [1] came into effect — a regulation which one occupational-health commentator described as producing "700 designated substances at the stroke of a pen". Nonetheless, it is still worth recording the few comments regarding designation of beryllium along with those of a more general nature.

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* We talked with the company management about this problem. They said it had been investigated by the Health & Safety Committee and traced to the introduction of a new brand of industrial soap which had caused rashes in seven other employees (none of whom were involved in machining copper-beryllium). The company has since returned to their original brand of soap.

5.2.1 Users of Beryllium Metal and Beryllia

The companies using beryllium metal and beryllia felt that the precautions they were taking and the procedures they had in place would be sufficient for any designated substance regulation the government might want to bring in. None of the companies contacted felt they had any problem with a time-weighted average exposure limit of 2 μg Be/m^3 (the now regulated TWAEV [1]). But an industrial hygienist with one of the companies manufacturing Candu fuel bundles felt that if a limit of 0.5 μg Be/m^3 were introduced (as had been suggested by NIOSH [38] and as is the current limit in Israel [34]) his company would have trouble complying. He suggested that the company might have to consider automating part of the brazing process and this action could lead to redundancies. The same person confessed to being uncertain as to which government agency had jurisdiction over his company's beryllium operation — the provincial Ministry of Labour or the federal Atomic Energy Control Board. He explained that while they still have regular inspections from the Ministry of Labour for safety they have not had an industrial hygiene inspection since 1980. Furthermore, the company had sent yearly summaries of beryllium exposure levels to the Atomic Energy Control Board, but recently (1985) has been asked by the Board to discontinue this practice. The complaint by an industrial health and safety officer with a company which machines beryllium metal that "most government regulations are so doggone vague no one knows what they should do", may well be apposite in this regard but, we suspect, is neither new nor confined to the question of beryllium regulations.

5.2.2 Users of Beryllium Alloys

An attempt was made during follow-up telephone interviews and plant visits to gather opinions among users of beryllium alloys on the question of designation and allowable exposure limits, but virtually no specific comments were received. The three examples which follow, however, probably come closest to addressing the question. The manager of an aluminum die-casting company was short and to the point:

> "We do not perceive any hazard from beryllium-copper and therefore no regulations are required. We do not contemplate any engineering measures to control exposure."

A representative of a company which is only occasionally asked to machine copper-beryllium observed:

> "Because we use beryllium-copper so rarely, we could easily drop the material if we found ourselves burdened by regulations."

And the production manager of a stamping operation which used copper-beryllium as one of its alloys, was of the opinion that

> "beryllium is not necessarily a candidate for designation but some regulation might be appropriate, especially if fumes were involved."

In this latter connection, it is noteworthy that some companies had decided to forbid welding of copper-beryllium and one company required workers to wear air-supplied respirators when welding [illegible]llium-containing alloys.

On the more practical question of how one might regulate beryllium exposure in the workplace, respondents typically indicated procedure-related solutions, as the following examples demonstrate:

> "It is company policy to require all machining operations involving beryllium-copper to be carried out using coolants,"
>
> "all our machining is carried out wet,"
>
> "we require employees to wear masks when grinding copper-beryllium," and
>
> "everyone knows you don't grind beryllium (i.e., copper-beryllium)."

Notwithstanding these assurances, we observed, and some respondents acknowledged, that machining and grinding of copper-beryllium without the benefit of cutting fluids sometimes occurred. It was also apparent that in some cases, both in foundries and machine shops, workers did not know if they were handling copper-beryllium or some other copper-based alloy; nor did they show much concern as to whether or not they indeed were.

It appears, therefore, that there is a gap in some instances between "theory" and practice. Perhaps the president of the union local at a foundry was right on target when he said,

> "education is the most important way of controlling beryllium exposure."

5.3 SUMMARY

No particular or pressing problems regarding the use of beryllium and its compounds were expressed by individuals contacted during this study.

Industries handling beryllium metal (precision machining and Candu fuel-rod manufacture) appeared to have a realistic awareness of the potential hazards of beryllium exposure. There was confidence that the precautions and procedures already adopted by these industries would be adequate for any designated substance regulation the government might want to introduce. None of the industries' representatives had any problem with a time-weighted average exposure value of 2 μg Be/m^3, but in one instance it was indicated that an exposure limit of 0.5 μg Be/m^3 would pose problems.

We gained an impression that there was a certain resistance in the microelectronics industry to the use of beryllia as a substrate material for microcircuits. There was a heightened awareness of the potential hazards associated with handling the material in the microelectronic environment. Nonetheless, there was confidence among those few companies who used, or were planning to use, beryllia that precautions currently employed in the industry for handling the ceramic would be sufficient to ensure compliance with any designated-substance type regulation the government might decide to implement.

There was less consensus among the different industries which use beryllium alloys. Perhaps a majority viewed beryllium exposure in their operations as presenting no hazard or as having a very low hazard potential. But certain activities (e.g., welding and dry grinding) were recognized as having a moderate hazard potential. No specific comments regarding either designation or appropriate exposure limits were received; rather remarks centered on procedure-related options. There was widespread acknowledgement, that machining and grinding of copper-beryllium should be carried out using coolants and cutting fluids. But such practices did not always occur.

6. REGULATORY CONSIDERATIONS

This chapter reviews the regulation of beryllium exposure, as an occupational concern, in foreign jurisdictions and in Canadian jurisdictions other than Ontario. As well, the current status of beryllium under Ontario's legislation is noted. Without making specific recommendations, the balance of the chapter discusses some regulatory issues and options for Ontario in the light of the information collected during the course of this study.

6.1 THE REGULATORY PROCESS IN ONTARIO

The *Occupational Health and Safety Act* provides the government of Ontario with broad ranging powers to prescribe regulations if there is reason to believe that exposure to a biological, chemical or physical agent may adversely affect the health of a worker [39]. For instance, the government may set a maximum exposure level (a performance standard) for the agent and require certain engineering controls, monitoring programs, medical examinations and worker education to ensure that the performance standard is met. Alternately, or additionally, the government may prohibit the use of certain agents or limit their use to certain specific applications. Instead of setting a performance standard, the government may require procedures, designed to ensure that exposure conditions will not adversely affect worker health, be carried out whenever a hazardous agent is used or is present (i.e., procedure standards). The government may also exempt certain activities or industrial sectors from the requirement to comply with specified regulations. Such a step may, for example, be taken because a particular industry does not possess the structural ability to ensure compliance (in which case regulatory control through the use of procedure standards may be more appropriate), or where the use of an agent does not cause sufficiently severe exposure to affect the health of workers.

The selection of the optimal strategy for the effective, efficient and equitable control of the exposure of workers to an occupational health hazard is essentially a public policy decision. The selection of policy instruments to carry out such a strategy is a complex, subtle and a necessarily political process [40]. A major challenge in regulating chemical health hazards is often the scientific uncertainty surrounding issues of causation of injury [41]. The difficulties in assembling a regulatory framework which accommodates scientific, economic, moral and political perspectives have been recognized in the literature [42].

It is beyond our mandate to make the public policy decisions which would select the mix of options to control worker exposure to beryllium. Rather, some of the pertinent options are discussed to provide background to any decision-making process.

6.2 REGULATION OF BERYLLIUM EXPOSURE IN OTHER COUNTRIES

Whenever regulatory reform is contemplated, it is worth reviewing the experience of other jurisdictions. The approaches other countries have taken in setting exposure standards and in establishing engineering procedures to reduce beryllium exposure can be helpful, particularly where it is clear that such specific issues as designating beryllium as a carcinogen have been addressed. It must be noted, however, that it is extremely rare for a jurisdiction's regulators to publish explicit descriptions of their policy selection process, particularly where the regulation of chemical hazards is concerned.

It follows from the subtlety and complexity of policy selection in chemical matters that regulatory decisions can rarely be transposed unmodified between jurisdictions, given differing philosophical, political, economic and legal traditions. (This, indeed, is a generally accepted caveat in comparative law and policy analysis.) In the case of exposure standards, for example, what is referred to as a "guideline" in an authoritarian country may be more rigorously applied than a "mandatory" standard in a country with liberal attitudes toward law enforcement or a country with a non-centralized or an ineffective bureaucracy.

6.2.1 Exposure Standards

Most industrial nations set exposure standards for hazardous agents encountered in the workplace. Table 6-1 presents a selection of exposure standards for beryllium in 12 countries, as well as the exposure standard suggested by the American Conference of Governmental Industrial Hygienists (ACGIH).

Most jurisdictions recognize the relatively high toxicity of beryllium, accepting a TWA exposure value of 2 μg/m^3 in most cases. Israel is the exception, having a very stringent standard of 0.5 μg/m^3. Short term exposure values and ceiling limits are quite variable. A review of ACGIH TLVs® reveals that beryllium and its compounds have the second lowest TLV-TWA (behind subtilisins) at 2 μg/m^3.

Most jurisdictions do not distinguish between pure beryllium and beryllium-containing materials or compounds in their regulatory standards. In the Swedish List of Limit Values [54], however, it is interesting to note that while "beryllium and compounds" are designated as sensitizing compounds, metallic beryllium is not considered to be sensitizing. The reasons for this exception are not stated and it is unclear from the Swedish document (at least from the English translation in our possession) as to what the term "metallic beryllium" refers.

6.2.2 Carcinogen Classification

Beryllium has been classified by the ACGIH as a substance suspected to have carcinogenic potential for human beings. Denmark, West Germany, Finland, Sweden, and the U.K. have all identified beryllium and its compounds as carcinogens, or suspected carcinogens. Normally attendant with such classification are special reporting requirements and specified control measures governing the use of beryllium-containing materials.

6.2.3 Engineering Controls and Other Measures

Most foreign jurisdictions have enacted regulations which contain provisions concerning ventilation or other controls relevant to the reduction of airborne contaminants in the workplace. OSHA's Safety and Health Standards, for example, contain the following requirements for using beryllium compounds:

> *Beryllium.* Welding or cutting indoors, outdoors, or in confined spaces involving beryllium-containing base or filler metals shall be done using local exhaust ventilation and airline respirators unless atmospheric tests under the most adverse conditions have established that the worker's exposure is within the acceptable concentrations defined by § 1910.1000. In all cases, workers in the immediate vicinity of the welding or cutting operations shall be protected as necessary by local exhaust ventilation or airline respirators. [62]

TABLE 6-1 Exposure Standards and Carcinogen Classifications in Some Non-Canadian Jurisdictions

Jurisdiction	Specified Beryllium Entity	TWAEL µg/m³	STEL µg/m³	Comments
AUSTRALIA				
a) New South Wales, Queensland, Tasmania, and South Australia [43]	Be and cpds.	2	- -	These Australian states use as guidelines the exposure limits recommended by the NHMRC, which in turn are adopted from the ACGIH TLVs®.
b) Victoria [44]	Be	2^{α}	- -	$^{\alpha}$ This is a maximum allowable concentration, not a TWA. An employer is not permitted to allow the concentration of Be in air breathed by a worker to exceed 2 µg/m³.
c) Western Australia [45]	- -	- -	- -	No specific laws or guidelines governing Be and compounds exist.
CZECHOSLOVAKIA [46]	Be and cpds.	1	2^{β}	Regulation. $^{\beta}$ Ceiling limit value.
DENMARK [47]	Be and cpds.	1	3	Be and compounds considered to be carcinogens, and therefore reporting provisions apply.
FEDERAL REPUBLIC OF GERMANY [48]	Be and cpds.	- -	- -	Recommendations. No MAK (maximum acceptable concentration) values. Be and compounds are listed as animal carcinogens with carcinogen potential. Technical Guiding Concentrations (TRK): (a) grinding of Be metal and alloys (Be in total dust): 5 µg/m³ (b) others: 2 µg/m³.
FEDERAL REPUBLIC OF GERMANY [49]	Be and cpds.	- -	- -	Regulation. A carcinogenic working material. Group I – very highly dangerous Group II – highly dangerous ≥ 10.0 g/kg (1.0%) Group III – dangerous <10.0–1.0 g/kg (<1.0 – 0.1%) The use and handling of materials in Groups I and II must be reported to the authorities, who may forbid the use of the material if a less harmful substitute exists.
FINLAND [50]	Be and cpds.	2	6	Be and compounds are considered to be carcinogens and therefore reporting provisions apply.

ISRAEL [51]	Be and cpds.	0.5	20^{γ}	$^{\gamma}$ STEL is 30 min. Specific Be engineering controls provided for, but not clear if they are statutory.
JAPAN [52]	Be and cpds.	- -	- -	"Allowable concentration" is 2 µg/m^3 and "administrative level" is 2 µg /m^3. Explanation of these terms is available only in Japanese.
NETHERLANDS [53]	Be	2	- -	The Maximum Acceptable Concentration (MAC) – TWA is used as a guideline.
SWEDEN [54]	Be and cpds.	2	- -	Considered to be carcinogenic and sensitizing (metallic Be is not considered to be sensitizing).
UNITED KINGDOM [55]	Be and cpds.	2	- -	Recommended limits used as part of criteria for assessing compliance with general statutory duties. Suspected of carcinogenic potential.
USA a) ACGIH [16]	Be and cpds.	2	- -	Recommendation. Suspected of carcinogenic potential for humans. Worker exposure by all routes should be carefully controlled to levels consistent with animal and human experience data.
b) OSHA [56]	Be and cpds.	2	5^{σ} 25^{ε}	Regulation. $^{\sigma}$ Acceptable ceiling concentration. $^{\varepsilon}$ Acceptable maximum peak (30 min.)
c) New Jersey [57] New York [58] Texas [59]		see OSHA		Rely on OSHA enforcement of the federal standard in their states.
d) Washington [60] California [61]		see OSHA		Issue their own standards, which for Be are the same as OSHA's.
USSR [46]	Be and cpds.	- -	1^{χ}	Regulation. $^{\chi}$ Ceiling limit value.

[ ] reference

TWAEL time-weighted average exposure limit

STEL short-term exposure limit

NHMRC National Health and Medical Research Council of Australia

Most other jurisdictions possess requirements of similar generality. We are aware, however, that in Israel detailed engineering controls and other workplace procedures are specified for a plant using beryllium metal [Table 6-2], and these are in addition to the very stringent exposure standards already mentioned [Table 6-1]. It is not clear from our correspondence with the Israeli authorities [51] which measures are mandatory and which are guidelines. Nevertheless, Table 6-2 sets out a coherent, integrated set of control measures which may be instructive. The success of these control measures has been studied and they have been found sufficient to bring the concentrations of beryllium in the plant to below the Israeli standards (see Gabbay *et al.* [34] and Table 4-1 of this report).

A number of countries now have warning and labelling systems for chemicals used in the workplace. Table 6-3 presents examples of such risk phrases required for beryllium and its compounds (except beryllium aluminum silicate) in Finland, which is fairly representative.

By virtue of being classified as a potential carcinogen, some jurisdictions require that monitoring, medical surveillance and training procedures be undertaken by establishments using beryllium. These provisions tend not to be specific for beryllium but are generally applicable to all compounds classified as potential carcinogens.

6.3 REGULATION OF BERYLLIUM EXPOSURE IN OTHER CANADIAN JURISDICTIONS

6.3.1 Exposure Standards

Presented in Table 6-4 are exposure standards for beryllium extant in Canadian jurisdictions other than Ontario. Two jurisdictions use the ACGIH TLVs® as a guide without specific regulatory adoption. Four jurisdictions have adopted the ACGIH TLVs® through regulations. Alberta, British Columbia, Quebec, Saskatchewan and the Yukon have established their own lists of exposure standards.

TABLE 6-2 Engineering Controls and Other Measures in Israel [51]

1. Engineering Controls

   A. a. The working area, where the rotating of Be is carried out is kept under sub-pressure conditions.

      b. Processing of Be is done by rotating and not grinding in order to avoid formation of particulates smaller than 10 μ.

      c. The quantity of Be in the working area should not exceed 1 kg at any time.

      d. Be should be stored in fire-proofed closets or safes.

      e. The places where Be is rotated should be closed and connected to hoods.

      f. All rotating machines operate with no hand touch.

   B. Cleaning System

   In the working area a blower draws air from the hoods (in which rotating machines are placed) to 2 cylcons in parallel. (Chips are collected in nylon bags). Then the air is passed through prefilters (87% efficiency for 0.5 μ particulates) and through absolute filters (99.97% efficiency for 0.3 μ particulates).

   Differential manometers measure the pressure drop across the prefilters and filters in order to check whether they are blocked or torn. The cleaned air is emitted out through the stack.

   Collected particulates and waste which were in contact with Be are sent with suitable labelling to a toxic waste disposal site.

2. Workers Training

   All workers were trained and instructed during 2 days before they began to work in the Be plant.

3. Labelling

   All solid wastes are collected in a box, fitted with warning and labelling signs. The labelling signs should include the content of the box, the physical state and the estimated quantity of Be.

4. Exposure Monitoring Requirements

   a. 3 personal samplers are stationed constantly on the rotating machines.

   b. Each person who works with Be carries a personal sampler.

   c. In addition each 2 weeks about 10 samples are taken by the Institute for Occupational Health.

   d. Emission measurements in the stack – 24 hours average.

   e. Monitoring of Be within the area of the factory (the control tower and restaurant). Each sample is a 24 hours average.

5. Medical Surveillance

   Each 6 months all workers pass medical tests: urine and blood tests, pulmonary and liver function tests, E.K.G., and chest X-ray.

TABLE 6-3 Risk Phrases Required for Beryllium* in the Workplace – Finland [50]

Warning Symbol: Toxic

Phrases:

- highly toxic when inhaled or swallowed
- irritating to the pulmonary system
- risk of serious irreversible noxious health effects
- if in eyes, flush immediately with plenty of water and consult a physician
- if on skin, flush immediately with plenty of water
- at accidents or at subjective feelings of overexposure, promptly call for medical attention
- prevent spreading of gas/vapor/fumes/spray in the air of the working place or arrange efficient ventilation or use suitable respiratory protection equipment

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* beryllium and compounds, except beryllium aluminum silicate

TABLE 6-4 Exposure Standards for Beryllium in Canadian Jurisdictions Other than Ontario

Jurisdiction	Specified Beryllium Entity	TWAEL $\mu g/m^3$	STEL $\mu g/m^3$	Comments
Canada (federal) [63]	Be and cpds.	2	- -	Regulation. No employee shall be exposed to a concentration in excess of the limit.
Alberta [64]	Be	2	6	Regulation. An employer shall ensure that the limits are not exceeded.
British Columbia [65]	Be	2	25	Regulation. A worker's exposure shall be limited to the standards.
Manitoba [66]	Be and cpds.	2	- -	ACGIH TLVs® used as a guide.
New Brunswick [67]	Be and cpds.	2	- -	An employer shall ensure that limits are not exceeded. Regulation adopts ACGIH TLVs® 1976.
Newfoundland [68]	Be and cpds.	2	- -	The limits shall not be exceeded. Regulation adopts ACGIH TLVs®.
Nova Scotia [69]	Be and cpds.	2	- -	An employer is to maintain the workplace in accordance with the standards. Regulation adopts ACGIH TLVs®.
Prince Edward Island [70]	Be and cpds.	2	20	ACGIH TLVs® used a a guide.
Quebec [71]	Be	2	20	Regulation. Limits must not be exceeded.
Saskatchewan [72]	Be	- -	- -	No limit provided. Be is classified as a Part V hazardous substance. Controls must be provided to prevent intake of Be into the body.
Northwest Territories [73]	Be and cpds.	2	- -	Regulation. Levels must be below limits or be satisfactory to the safety officer. Limits adopted from ACGIH TLVs®.
Yukon [74]	Be	2	- -	Regulation. Worker's exposure to be limited to stated concentrations.

TWAEL time-weighted average exposure limit

STEL short-term exposure limit

Saskatchewan is the only Canadian jurisdiction which does not have an exposure limit for beryllium. All the others have a TWA exposure limit of 2 μg/m^3. The short term exposure limits for Alberta, British Columbia and Quebec vary, being 6, 25 and 20 μg/m^3, respectively.

Not including Ontario, five Canadian jurisdictions have exposure limits for "beryllium", and seven have exposure limits for "beryllium and compounds, as beryllium". The latter phrase is the ACGIH wording, although in the ACGIH carcinogen appendix the wording is simply "beryllium". Is this a distinction without a difference? British Columbia's exposure list, for example, refers to "beryllium", but for other elements, the list frequently includes their compounds (e.g., "manganese and compounds, as Mn"). This raises the presumption that the exclusion of "... and compounds" means there is a deliberate concern for pure beryllium, but not for beryllium compounds. On the other hand, it is quite likely that the question has not been considered much, if at all, since regulators seem to copy exposure limits established elsewhere, rather than develop their own.

6.3.2 Carcinogen and Special Classification

As illustrated in Table 6-5, most Canadian jurisdictions list beryllium as a suspected carcinogen by virtue of adopting, using or copying the ACGIH list. Of the six provinces which have published their own lists of exposure limits, all but Ontario have singled beryllium out for special classification (usually along with 20 to 40 other substances) as either a suspected carcinogen or a hazardous chemical requiring extra precautionary measures. Nevertheless, there is no specific regulatory treatment of beryllium along the lines of an Ontario designated substance regulation.

6.3.3 Engineering Controls and Other Measures

All Canadian jurisdictions have enacted provisions in their occupational regulations requiring engineering controls, such as ventilation, for airborne contaminants. Virtually all such provisions are performance rather than procedure standards. Some requirements are more extensive than others. None are specific for beryllium. Ventilation provisions in the regulations of Canadian jurisdictions have been reviewed extensively elsewhere (see, for example, Holliday *et al.* [reference 30, chapter 6]) and will not be repeated here.

TABLE 6-5 Carcinogen or Other Special Classification for Beryllium in Canadian Jurisdictions

Jurisdiction	Classification*
Canada (federal), Manitoba New Brunswick, Newfoundland Nova Scotia, PEI, NWT	By virtue of adopting or using the ACGIH system, beryllium is classified as a substance suspected of carcinogenic potential for humans [Appendix A2 of ACGIH].
Alberta	Beryllium is listed in Schedule C of the regulations. This schedule contains many known and suspected carcinogens, but the schedule is not described as such. Notification and control measure approval provisions apply to Schedule C substances [s.6,7].
British Columbia	Beryllium is listed in Appendix B of the regulations as a carcinogen (33 substances listed). It is a Table 1 "carcinogen with a permitted exposure" (23 listed). Labelling and disposal provisions apply [s.12.23 and s.12.25].
Quebec	Beryllium is designated as a "substance considered a carcinogen" in Part V of Schedule A of the regulations (39 substances listed). As such, restrictions apply – no recirculation of a Part V substance in any air recirculation system is permitted [s.21].
Saskatchewan	Beryllium is *not* classified as a Part IV carcinogen (17 substances listed), but is classified as a Part V "hazardous chemical substance". The employer shall ensure that adequate engineering controls and suitable personal protective equipment are provided to prevent intake of Part V substances into the body [s.71].
Yukon	Beryllium is listed in Table 14 of the regulations as a carcinogen with a permitted exposure [22 substances listed].

* Schedules, Parts, Tables and Section numbers refer to regulations cited in Table 6-4.

Beryllium has not been singled out under any Canadian occupational regulatory regime for specific control measures other than those which may apply to potential carcinogens.

6.4 THE CURRENT SITUATION IN ONTARIO

There have been some recent developments in Ontario of significance. Effective December 6, 1986, Ontario established its own list of exposure standards by regulation. The ACGIH TLVs® are no longer used as guidelines in Ontario. The *Regulation Respecting Control of Exposure to Biological or Chemical Agents* [1], which will be referred to as the "Exposure Control Regulation", establishes a mandatory exposure value for beryllium and its compounds of 2 $\mu g/m^3$ — the same TWA exposure value as the ACGIH TLVs®. An employer has a general duty to take "all measures reasonably necessary in the circumstances to protect workers from exposure to" beryllium "because of the storage, handling, processing or use" of beryllium "in the workplace" [reference 1, s. 3(1)]. The measures to be taken are to include engineering controls, work practices, hygiene facilities, and as a last resort, personal protective equipment [reference 1, s. 3(2)]. Without limiting the scope of the general duty, the employer is to take the above measures to "limit the daily and weekly exposure of workers" to the established exposure values [reference 1, s. 4(1)].

It is noted that although beryllium does not have a specific short term exposure value (STEV) listed in the schedule to the regulation, the preamble to the list (part 2B) requires that a that a worker shall not be exposed to a concentration that exceeds:

(a) three times the TWAEV for any period of 30 minutes, which for beryllium and compounds is 6 $\mu g/m^3$, and

(b) five times the TWAEV for any period of time, which for beryllium is 10 $\mu g/m^3$.

Although not identified as STEVS as such, these short term exposure values are in the same range as short term exposure values set out for other jurisdictions in Tables 6-1 and 6-4.

With the advent of the Exposure Control Regulation there are now two routes by which mandatory exposure values may be set in Ontario, the other being the designated substance approach. A major policy question to be addressed in the next section is whether the establishment of the duties under the Exposure Control Regulation are sufficient for controlling beryllium exposure, or whether the additional measures required by a typical designated substance regulation (monitoring, medical surveillance, control program, training) are needed.

The Exposure Control Regulation also establishes, for the first time, a list of "known toxic agents" for which exposure values have not been established, and to which any exposure should be avoided [reference 1, part 10]. The word "carcinogens" is not used to describe this list of known toxic agents, but most of the 15 substances listed are recognized or suspected by the ACGIH to be carcinogens. We can assume that beryllium is left off the list because it has been assigned a TWAEV.

The Exposure Control Regulation amends the *Regulations for Mines and Mining Plants* [75] to require that ventilation in a mining plant building and in an underground mine be capable of reducing exposure to hazardous substances (e.g., beryllium) to below the new exposure values [reference 1, s. 11(3)]. Beryllium is not, however, mined in Ontario and there is no evidence that beryllium is a contaminant in Ontario mining workplaces. The Exposure Control Regulation does not apply to the construction industry [reference 1, s. 2].

Sections of interest in the *Regulations for Industrial Establishments* [76] are general housekeeping and ventilation provisions which state that the removal of material from the workplace shall be done in such a way as not to cause a hazard and that ventilation shall be adequate such that the workplace atmosphere does not endanger the health of workers [reference 76, s. 130 and s. 131]. Air brought into the work area to replace air exhausted to the outside is to be free from contamination with any hazardous dust and shall "enter in such a manner so as to prevent blowing of settled dust into the workplace" [reference 76, s. 132]. Since only Section 145 of the industrial regulations is repealed by the Exposure Control Regulation, these general housekeeping and ventilation provisions remain in effect.

It is noted that beryllium and compounds are listed in Schedule 3 of the *Regulation 951 (General)* [77] of the Ontario *Workers' Compensation Act* [78]. Section 122(a) of this Act raises the presumption that where a worker is employed in any process involving "the use of beryllium or its preparations or compounds", beryllium "poisoning" is deemed to have been due to the nature of the employment unless the contrary is proved. It is interesting to note, in this regard, that two claims for beryllium poisoning were allowed in the period 1977 to 1986; both were in the electronics industry [79].

6.5 CONSIDERATIONS FOR ONTARIO

It is not the intention of this report to recommend that Ontario choose specific options or mix of options with regard to occupational exposure to beryllium. Rather, in delineating these options, a description of the various considerations which may be pertinent to their acceptance or rejection is presented. Though an attempt is made to illuminate the tensions between these considerations, no assessment of their appropriateness or validity is given or implied.

Five major regulatory pathways are outlined in order to highlight some of the considerations a regulator may want to assess before deciding on an appropriate course of action. In addition, a number of specific issues which have some bearing on these options are discussed separately.

6.5.1 Regulatory Options

6.5.1.1 Option 1 — Do nothing: The status quo is maintained. Exposure values for beryllium remain as established by the new Exposure Control Regulation, namely a TWA exposure value of 2 $\mu g/m^3$, the same as that extant in most other relevant jurisdictions, and short term exposure values of 6 $\mu g/m^3$ (30 min.) and 10 $\mu g/m^3$ (any period).

Maintaining the status quo implies that the Ministry considers current levels of beryllium exposure pose little threat to worker health. Exposure limits for beryllium would remain in the same range as those limits established in other jurisdictions, except for the stringent Israeli standards. The status quo also suggests that it is not necessary to categorize beryllium as a suspected carcinogen — as many other jurisdictions have done.

The "do nothing" option is not unattractive since the few employers in the province using pure beryllium metal or beryllia appeared to be quite aware of the potential hazards and appeared to have extensive control measures in place. Moreover, the Exposure Control Regulation is new and it is too early to know whether the mandatory nature of the exposure limits therein, or the general section 3 duty (see Section 6.4), will result in an increased level of vigilance in Ontario workplaces without further regulatory standards. Finally, as noted elsewhere in this report [Chapter 4], there were no respondents who indicated that time-weighted-average exposure levels measured in their workplace exceeded 2 $\mu g/m^3$. However, since actual measurement of exposure levels was not a part of this study, we do not have available a assessment of what exposure levels currently are in the province.

While prevention of non-carcinogenic effects of beryllium might be accomplished by the current exposure limits, it is much more difficult to say that the limits are sufficient for prevention of cancer, since causality for chemical carcinogenesis is notoriously difficult to establish. There are those who insist that chemical carcinogen use should be prohibited or strictly curtailed wherever possible even in the face of causal uncertainty [80].

6.5.1.2 Option 2 — Waiting for WHMIS: In June 1987, the federal and Ontario governments passed legislation to implement the Workplace Hazardous Materials Information System (WHMIS). The provisions of both the provincial legislation, *An Act to amend the Occupational Health and Safety Act* (Bill 79) [81], and the federal legislation, *An Act to amend the Hazardous Products Act* (Bill C-70) [82], take effect on 31 October 1988. In essence the purpose of WHMIS is to provide uniform standards for Canada-wide delivery of labels, material safety data sheets (MSDS) and worker education programs. The underlying philosophy is that an increased flow of quality information on hazards in the workplace will strengthen the ability of participants in the "internal responsibility system", embodied in most provincial health and safety legislation, to control exposure levels to hazardous substances. Since the federal legislation will set the national standards for labels and MSDSs, and since those standards will be largely "performance standards", there is little that would remain to be done specifically for beryllium by the Ministry. Therefore, the "waiting for WHMIS" option is a variation on Option 1.

6.5.1.3 Option 3 — Advice and education: This is also a non-regulatory option insofar as regulations specific for beryllium are concerned; Option 3 is related to Option 2. Under WHMIS, worker education programs must be established, but the content of the education program in each workplace is not dictated. For processes and industries where the levels of beryllium might be expected to be a concern (e.g., where pure beryllium is used or where inappropriate machining practices for copper-beryllium are used), the Ministry could prepare and deliver education materials to assist employers in setting up their education programs under WHMIS, and in addition, provide technical advice for engineering controls.

6.5.1.4 Option 4 — Amendment of current regulations: As opposed to enacting a beryllium designated substance regulation [Option 5], the Ministry may consider amending the Exposure Control Regulation to do either or both of the following:

(i) change the exposure limit for beryllium and compounds, now set at 2 $\mu g/m^3$.
(ii) place beryllium on the Part 10 *de facto* suspected carcinogen list.

Until the advent of the Exposure Control Regulation, there was a large leap in regulatory stringency between the general duties under the Occupational Health and Safety Act plus ACGIH guidelines and a full-fledged designated substance control regulation. Option 4, the use of the Exposure Control Regulation, represents a mid-course, previously unavailable.

The choice between Option 4 and a designated substance regulation is discussed below [Section 6.5.1.5], as is the question of an appropriate exposure limit [Section 6.5.2.2]. As for adding beryllium to the part 10 *de facto* carcinogen list in the Exposure Control Regulation, the decision to do this requires that the Ministry be satisfied that any exposure to beryllium should be avoided. For that end, an exposure value for beryllium would be abandoned. Such special attention is a relatively high profile regulatory act having a strong educational and motivational effect in itself, and, as far as awareness is concerned, would have a similar impact as designation. Given that beryllium is identified as a suspected carcinogen in a number of jurisdictions and that the exposure limit is already very low, it could be argued that it would be a small, uncontroversial move to add beryllium to the Part 10 list.

6.5.1.5 Option 5 — Designated substance regulation: Under this option, beryllium would be regulated as a "designated substance" in a manner similar to the current regulation of benzene, silica, asbestos, etc. The beryllium regulation would prescribe limits and provide for monitoring of exposure, workplace assessments, development of control programs, record-keeping, etc., as do the current designated substance regulations.

It may be observed that a characteristic of most of the substances already designated is their wide use or presence in industry. Devising procedural standards in such circumstances is considered impractical, which is why designated substance regulations set out performance standards (exposure limits) and use the "internal responsibility system" (via joint health and safety committees) to devise "exposure control programs", which are specific for each workplace in which the substance is encountered. If the use of beryllium alloys is excluded from consideration, it can be observed that beryllium-containing material is used in such few Ontario establishments that one may question whether it should enjoy the stringent regulation covering the much more widely used current designated substances. It could be argued that close observation of the few beryllium-using workplaces, along with strict enforcement of the Exposure Control Regulation, might be sufficient regulatory action.

While the use patterns for beryllium might appear to favour Option 4 over Option 5, it might be argued that the health effects of beryllium suggest otherwise. Summarizing very briefly from Section 2.2, these are as follows:

- acute beryllium intoxication (a form of chemical pneumonitis);
- chronic beryllium disease (berylliosis) with a potential latency period of up to 20 years;
- a wide range in individual susceptibility;
- deep ulceration of skin abrasions and cuts contaminated with the soluble salts of beryllium; and
- suspected carcinogenicity.

Latency periods, individual susceptibility and suspected carcinogenicity are characteristics of a substance which require medical surveillance, record-keeping, and education programs. These activities are typical of the types of action required under a designated substance regulation.

6.5.2 Specific Regulatory Aspects

6.5.2.1 Definition: To regulate, it is necessary to have a definition of what is regulated. If beryllium-containing materials are to be regulated, there is no doubt that pure beryllium ought to be regulated. But, for example, should copper-beryllium alloys be covered as well? Beryllium concentrations in most copper-beryllium alloys are low and many of the manufacturing processes, such as stamping and cutting, used on the alloys produce little airborne beryllium. If a designated substance regulation is contemplated, consideration might therefore be given to exempting workplaces where copper-beryllium alloys are used in certain specified processes.

If certain beryllium compounds, and not others, are responsible for deep ulceration of contaminated cuts, then these compounds might be singled out for special consideration. The notation "skin" in exposure limit lists refers to skin as a route of absorption, not as a site of localized harm, and so such notation would be an insufficient warning. "Exposure" in the Exposure Control Regulation includes skin contact, but airborne exposure values are, of course, inappropriate for regulating skin contact. Hence, consideration might be given to concentration limits for surface areas ($\mu g/m^2$) using a "swipe test", but only for beryllium compounds causing deep ulceration.

6.5.2.2 Selection of exposure limit: To discuss the selection of a specific exposure limit, one needs, first of all, a very clear picture of the types and severity of injury a substance can cause, as well as an assessment of probability of various health effects occurring in different circumstances. To actually select an exposure limit, one needs, in addition to a scientific assessment, a normative theoretical framework (including moral, political and economic elements) under which a degree of risk, if any, is accepted. No regulatory agency, to our knowledge, has ever published a formal declaration of such a normative framework.

Yet, a number of comments can be made here. If a selected exposure value for beryllium is to be close to the "lowest practical level", then it could be argued that 2 $\mu g/m^3$ is too high. This is because there was some evidence from our study that airborne beryllium levels do tend to be lower than 2 $\mu g/m^3$, and are often undetectable in some beryllium-material using processes. (It is to be noted that this evidence is anecdotal, as a systematic survey of existing levels was not performed.) In addition, evidence from the literature suggests that even the very stringent Israeli standard of 0.5 $\mu g/m^3$ can be met in an industry where beryllium is machined [34].

If it is true that individual susceptibility to beryllium varies, then it might be said that a TWAEV of 2 $\mu g/m^3$, which is the same as the ACGIH TLV®, is inappropriate, since a TLV®, by definition applies to "nearly all workers", and no such caveat exists for exposure values in the Exposure Control Regulation. Putting it another way, the exposure value in the Exposure Control Regulation implicitly covers all workers, not nearly all workers. For a substance such as beryllium, which apparently has a recognized characteristic of individual susceptibility, the exposure value must be lower than 2 $\mu g/m^3$ if it purports to be mandatory for all workers.

If beryllium is not placed on the Part 10 list, then consideration should still be given to how substantive the evidence for carcinogenesis is. Although beryllium may be a "suspected" carcinogen and not a "proven" carcinogen, the question to be addressed is whether an exposure standard should take into account the status of "suspected" carcinogen.

6.5.2.3 Ancillary programs: Certain programs and practices, other than, or in addition to, exposure limits, may be used to reduce exposure to beryllium. These programs and practices may be implicitly involved in meeting a "performance standard" such as an exposure limit, or they may be directly required in a designated substance regulation.

There is little doubt that exposure to beryllium can be substantially reduced if effective local ventilation were to be in place. And, indeed, extensive engineering controls and hygiene practices were observed to be in place in companies using pure beryllium and beryllia [Section 4.1 and 4.2]. These included complete enclosure of machinery, precise application of local ventilation, work areas accessible solely through air locks, on-site machine washing of cover-alls, alarm systems and evacuation and emergency clean-up procedures where spills occur, and so forth. On the other hand, in some establishments where copper-beryllium alloys were used, we observed chips of copper beryllium piled in heaps on the floor around machinery and workers polishing copper-beryllium surfaces with unprotected hands. The variation in practices reflected the differing concerns over pure beryllium and copper-beryllium alloys.

If hygiene practices, engineering controls, monitoring or medical surveillance specific to beryllium are to be specified by regulation, the different risks posed by the use of pure beryllium and the use of copper-beryllium alloys should be taken into account. As noted earlier, such specific regulations might exempt industries and processes using copper-beryllium.

It would seem from what is known about the health effects of beryllium exposure (listed generally above), that a requirement for medical surveillance, particularly where pure beryllium is used, merits special consideration. This may be accomplished in a "blanket" manner by incorporating such a requirement in a designated substance regulation or, perhaps, at an individual-worker level through the Section 8 provisions of the Exposure Control regulations [reference 1, s. 8(1)c].

In Ontario, employers have a statutory duty to provide information, instruction and supervision to workers to protect their health. To augment this general duty, proposals such as WHMIS have been designed to increase the availability of hazard information and to ensure that workers understand hazard information through education. In practice, implementation of WHMIS in October 1988 will likely supersede many of the previous regulatory requirements for training and education, including requirements in designated substance regulations.

6.6 SUMMARY

Ontario's Exposure Control Regulations mandate a TWAEV of 2 μg Be/m^3. This exposure standard is consistent with the ACGIH TLV® guidelines and the exposure standards of most foreign and domestic jurisdictions examined during this study. Some countries, however, have adopted more stringent exposure standards (e.g., 1 μg/m^3 in Czechoslovakia, Denmark and the U.S.S.R., and 0.5 μg/m^3 in Israel). Along with the ACGIH, most jurisdictions classify beryllium and its compounds as suspected carcinogens and usually attendant with this classification are specific work-practice and ventilation-control stipulations. Beryllium and its compounds are not classified as carcinogens under

Ontario regulations. It was pointed out that such a classification could, in principle, be effected by adding beryllium and its compounds to the Part 10 list of known toxic agents in the Exposure Control Regulations, because the majority of 15 substances already on the list are either proven or suspected human carcinogens. It was noted, however, that if thise course were adopted, the TWAEV requirements would be dropped and replaced by the more stringent requirement that "any exposure" to beryllium "should be avoided".

If it were decided that the scope of the Exposure Control Regulation was insufficient to ensure adequate worker protection, the detailed requirements of a designated substance regulation might be considered. However, it could be argued that such a regulation could legitimately exempt industries or processes using copper-beryllium alloys (perhaps with specified beryllium content) and focus on those workplaces using pure beryllium (and compounds with high beryllium content). Industries using beryllium tend to be small in number and relatively sophisticated technologically, hence a focused program of engineering control advice might be an effective and efficient means of reducing beryllium exposure. Because of what is known about the health effects of beryllium (latency, individual susceptibility and suspected carcinogenicity) it was pointed out that mandatory medical surveillance programs for certain workplaces might be an option worth considering.

The introduction of WHMIS in October 1988 will increase the availability of information regarding hazardous materials and, ideally, will ensure through required education programs that workers better understand the hazards that the use of such materials present. The WHMIS provisions largely obviate the need to introduce specific regulatory requirements for training and education (e.g., through a designated substance regulation for beryllium) which might otherwise have been needed under the present provisions of the Occupational Health and Safety Act.

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I. CONTACTS MADE DURING THE PROJECT

Listed in this appendix are the companies, trade and professional associations, labour unions, and governmental agencies contacted during the study. The methods used in the contacts are indicated as follows:

T	telephone interview,
L	letter,
M	face-to-face meeting, and
V	plant visit.

In order to give some idea as to the type of activity in which the contacted companies are involved, the *a priori* industry grouping (described in detail in Appendix III [Section III.1.1]) is identified against each company name in Sections I-1 and I-2:

Auto.	automobile manufacture,
Avion.	manufacture of aircraft, avionic parts, and spacecraft related hardware,
B&B	bearing manufacturers and screw-machine shops,
Die	aluminum die casting establishments,
Elec.	manufacture of electrical contacts, connectors, and switchgear,
Found.	non-ferrous foundry operations,
House	major household appliance manufacture,
Mould	a selection of tool and die makers, and machine shops specializing in making mould for plastics' moulding,
SS	manufacture of solid-state circuits and allied electronics,
Spring	manufacture of springs and related items, and
Misc.	a variety of companies including some associated with the nuclear industry, medical equipment manufacture, resistance welding, etc.

I.1 COMPANIES SENT THE MAIL-OUT QUESTIONNAIRE

The 172 establishments, representing 156 different companies, sent the mail-out questionnaire survey [Appendix III, Section III-1] are listed below. Those establishments which responded to the survey are indicated with an "(R)". Of the respondents, 81 establishments used (or had used) beryllium-containing materials in their activities [Section III.3.2]. Of these establishments, 53 were contacted for in-depth telephone interview and

11 were visited [Section III.2]. In order to protect anonymity in the descriptions presented in the body of this report [Chapters 3, 4 and 5], the establishments are not identified with a "T" and a "V" in the list presented below:

Die	ACF Canada, Brampton	L (R)
Elec.	AMP Canada, Markham	L
Mould	ARCO Machine & Tool Co., Scarborough	L
Die	Amcan Castings, Hamilton	L (R)
Elec.	Amerace, Markham	L (R)
Elec.	American Superior Electric, Toronto	L (R)
Die	Arrowhead Metals, Toronto	L (R)
Spring	Arrow Spring & Tool Co., Brampton	L (R)
Mould	Arrow Tool & Die Manufacturing Co., Hamilton	L (R)
Misc.	Atomic Energy of Canada, Chalk River	L
Elec.	Augat Electronics, Mississauga	L (R)
Misc.	Auro Metals, Guelph	L
Spring	Automated Spring Industries, Mississauga	L (R)
B&B	Babcock and Wilcox, Cambridge	L
Spring	The Barnes Wallace Co., Burlington	L (R)
Misc.	Bata Industries, Battawa	L (R)
Mould	Blow Mold Tooling, Malton	L (R)
Avion.	Boeing of Canada, Arnprior	L (R)
Spring	Bohne Spring Industries, Etobicoke	L (R)
B&B	J.K.S. Boyles, Toronto	L (R)
Die	Brampton Foundries, Brampton	L
Die	Burlington Die Castings, Burlington	L
Elec.	Burndy Inc., Scarborough	L
Elec.	Burndy Inc., Markham	L (R)
Die	CAE Accurcast, Wallaceburg	L (R)
Die	CAE Webster	L (R)
SS	CDC Canada, Ottawa	L (R)
Elec.	Cable Assembly Systems, Brantford	L
House	Camco Inc., Mississauga	L (R)
B&B	Canada Metal Co., Toronto	L (R)
Elec.	Canada Wire & Cable, Don Mills	L (R)
Die	Canadian General Electric, Trenton	L
Misc.	Canadian General Electric, Peterborough	L (R)
Elec.	Canadian General Electric, Guelph	L
SS	Canadian Marconi, Kanata	L (R)
Mould	Canron Inc., Toronto	L (R)
Die	Carpenter Die Casting, Stoney Creek	L (R)
Misc.	Centaur Manufacturing Co., Richmond Hill	L (R)
Mould	Center Tool & Mold Co., Windsor	L (R)
Found.	Cercor Inc., Halton Hills	L
Elec.	A.B. Chance of Canada, Scarborough	L (R)
Auto.	Chysler Canada, Windsor	L (R)
B&B	Collinson-Goll, Weston	L
SS	Com Dev, Cambridge	L (R)
Elec.	Commander Electrical Equipment, Scarborough	L (R)

SS	Communications Devices Inc., Toronto	L (R)
Misc.	Coopers Iron & Metal Inc., Toronto	L (R)
Misc.	Cramco Alloy Sales, Scarborough	L (R)
Avion.	De Haviland, Downsview	L (R)
Found.	Designed Precision Castings, Brampton	L (R)
Spring	Dominion Spring Industries, Mississauga	L (R)
Mould	Dual Machine Products, Mississauga	L (R)
Elec.	Electrical Contacts, Hanover	L (R)
House.	Electrohome, Kitchener	L
Die	Electrohome, Cambridge	L (R)
Elec.	Electrohome, Niagara	L (R)
Die	Electroline Manufacturing Co, Windsor	L (R)
Die	Emhart Canada, Belleville	L (R)
Elec.	Erico, Toronto	L
Die	Etatech Industries, Brantford	L
Mould	Excel Mold, Mississauga	L
B&B	FAG Bearings, Stratford	L (R)
Elec.	Federal Pioneer, Toronto	L (R)
Die	Fisher & Son, Stoney Creek	L (R)
Avion.	Fleet Aerospace, Fort Erie	L (R)
Auto.	Ford Motor Co., Oakville	L (R)
Die	Franklin Electric, Strathroy	L (R)
Elec.	GLE Inc., Toronto	L
SS	Garrett Manufacturing, Rexdale	L (R)
Auto.	General Motors, Oshawa	L (R)
Misc.	General Production Devices, Gormley	L (R)
Misc.	Gibb Wire & Steel Co., Brampton	L (R)
Elec.	Gould Shawmut Co., Toronto	L (R)
Mould	Grimsby Custom Tooling, Stoney Creek	L
Die	Gulan Die Casting, Mississauga	L
Found.	Haley Industries, Haley Station	L (R)
Spring	Hamilton Wire Products, Hamilton	L (R)
Spring	Henderson Manufacturing, Stratford	L
House	Hoover Canada Inc., Burlington	L
Elec.	IDI Electric, Ajax	L (R)
Elec.	ILSCO Canada, Mississauga	L (R)
Elec.	ITT Industries of Canada, Toronto	L
Elec.	ITT Industries of Canada, Whitby	L (R)
SS	ITT Industries of Canda, Concord	L (R)
Found.	Industrial Fine Castings, Caledon	L (R)
House	Inglis, Stoney Creek	L (R)
House	Inglis, Mississauga	L (R)
Mould	International Tools, Windsor	L (R)
Mould	JFJ Mold Processors, Oldcastle	L
Found.	Johnson Matthey, St. Catharines	L (R)
Found.	Johnson Matthey, Toronto	L (R)
Found.	Johnson Matthey, Brampton	L
Die	Jutras Die Casting, Agincourt	L
B&B	Keeprite Inc., Brampton	L (R)
Found.	Kern's Foundry Inc., Windsor	L
Misc.	Kilian Manufacturing, Toronto	L

Misc.	Kodak Canada, Toronto	L (R)
Die	Lamco Die Cast, Thorold	L (R)
Mould	Lamko Tool & Mold, London	L
Die	Lawton Diecast of Canada, Strathroy	L (R)
SS	Linear Technology, Burlington	L (R)
Avion.	Litton Systems Canada, Etobicoke	L (R)
Misc.	Longyear Canada, North Bay	L (R)
SS	Lumonics Inc., Kanata	L (R)
SS	Magna Electronics, Scarborough	L (R)
B&B	Maple Screw Products, Mississauga	L (R)
Spring	Maverick Spring Makers, Brantford	L (R)
Die	Medallion Fence, Maple	L (R)
SS	Microtel, Brockville	L
Elec.	Molex Electronics, Scarborough	L (R)
Die	Multifittings, London	L
Spring	Newcomb Spring of Canada, Toronto	L (R)
SS	Northern Telecom Canada, Mississauga	L (R)
Mould	Nyab Vicom, Kingston	L (R)
Misc.	OHMA Systems Inc., La Salle	L (R)
Misc.	Ontario Hydro, Toronto	L (R)
Die	Outboard Marine, Peterborough	L (R)
Elec.	Panduit Canada, Markham	L
Die	Parkway Manufacturing, Kitchener	L (R)
Misc.	Peckover's, Concord	L
Spring	Perfection Automotive Products, Windsor	L
Elec.	Phillips Cables, Brockville	L
Elec.	Phillips Cables, Scarborough	L
Mould	Phillips Tool & Mold, London	L (R)
Misc.	Picker International Canada, Brampton	L (R)
Elec.	Planar Circuits, St. Catharines	L (R)
Mould	Plastic Moulders, Toronto	L (R)
Spring	Precision Spring of Canada, Kingsville	L
Mould	Precision Valve, Ajax	L (R)
Spring	Premier Spring & Manufacturing, Ayr	L (R)
Elec.	W.C. Pursley, Mississauga	L (R)
Elec.	Pyle National of Canada, Mississauga	L (R)
Elec.	Pyrotenax of Canada, Trenton	L (R)
Misc.	Radiochemical Co., Kanata	L (R)
Die	Ramsden Industries, London	L
Elec.	Renfrew Electric Co., Scarborough	L (R)
Misc.	Resistance Welding Products, Blenheim	L
Die	Richmond Die Castings, Cornwall	L (R)
Spring, Misc.	Rockwell International of Canada, Toronto	L (R)
Mould	Ryka Blow Molds, Mississauga	L (R)
Elec.	Schlumberger Canada, Toronto	L (R)
Elec.	Siemens Electric, Mississauga	L
SS	Siltronics, Kanata	L (R)
Elec.	Smith & Stone, Halton Hills	L (R)
Avion.	Spar Aerospace, Mississauga	L (R)
Avion.	Sperry Inc., Ottawa	L (R)
Avion.	Sperry Inc., Rockland	L (R)

Spring	Springco Industries, Toronto	L (R)
Elec.	Square D Canada Inc., Waterloo	L (R)
Spring	Steele's Wire Springs, Guelph	L (R)
Mould	Strathearn House Group, Concord	L (R)
Found.	Supreme Casting & Tooling, Rexdale	L (R)
Elec.	3M Canada, London	L
SS	Torga Electronics Systems, Ottawa	L
Mould	Tesan Mold Inc., Downsview	L
B&B	Therm-O-Disc Canada, St. Thomas	L (R)
Spring	Timbren Industries Inc., Ajax	L (R)
Mould	Tradesco Mold, Rexdale	L (R)
Mould	Triangle Plastics, Port Colborne	L (R)
Misc.	Union Carbide Canada, Brampton	L (R)
Die	H.E. Vannatter, Wallaceburg	L (R)
Mould	Verral Metal Fabricators, Scarborough	L (R)
House	WCI Canada, Mississauga	L (R)
Spring	P.J. Wallbank Manufacturing, Plattsville	L (R)
Die, Found., Mould	Waltec Inc., Cambridge	L (R)
Misc	I. Waxman & Sons, Stoney Creek	L (R)
Mould	Wentworth Mould & Die, Hamilton	L (R)
Misc.	Westinghouse Canada Inc., Port Hope	L (R)
House	Westinghouse Canada Inc., Hamilton	L
Mould	Windsor Match Plate & Tool, Windsor	L (R)
B&B	Zenith Screw Co., Rexdale	L (R)
SS	Zentronics, Brampton	L (R)

I.2 OTHER COMPANIES CONTACTED

In addition to the companies involved in the industry survey, we obtained information from a number of other companies:

¶	Brush Wellman Inc., Cleveland, OH	T,L
¶	Brush Wellman Inc., Colmar, PA	T,L,M*
Misc.	Consumers Glass, Milton	T
SS	Epitek, Kanata	V
Found.	Gamma Foundries, Richmond Hill	T
Found.	Oliver Canada, Orillia	T
¶	NKG Metals Corporation, Reading, PA	T,L

¶ Primary producers of beryllium, beryllia and beryllium alloys

* Meeting, in Ottawa, with company representative

I.3 TRADE UNIONS, PROFESSIONAL AND TRADE ASSOCIATIONS

Information concerning the ways in which beryllium-containing materials are used in Ontario and the companies which might be using such materials was sought from trade unions, trade associations and other professional bodies. In addition, where an organized labour force existed, local union representatives were contacted during plant visits.

Canadian Advanced Technology Association, Ottawa	L, M
Canadian Automotive Workers, Willowdale	T, L, M
Canadian Die Casters Association, Toronto	T
Canadian Foundry Association, Ottawa	T
Canadian Nuclear Association, Toronto	T
Canadian Tooling Manufacturers Association, Toronto	T
Copper & Brass Development Association, Toronto	T
Electrical & Electronic Manufacturers Association, Toronto	T, M
International Association of Machinists, Ottawa	L, M
International Molders & Allied Workers Union, Toronto	T
Ontario Association of Certified Engineering Technicians and Technologists	T
Ontario Center for Automotive Parts Technology, St. Catharines	T
United Electrical Workers, Don Mills	T
United Steelworkers of America, Toronto	T, L, M
Welding Institute of Canada, Oakville	T

I.4 GOVERNMENT AGENCIES

Letters of enquiry concerning regulatory approaches to the control of worker exposure to beryllium and its compounds were sent to a number of countries. The purpose of these enquiries was to obtain information on: exposure limits, engineering controls, worker training, labelling, exposure monitoring requirements, and medical surveillance. With the exception of Québec, letters of enquiry were not sent to the Canadian provinces or the federal government, as we already had published occupational health and safety material for these jurisdictions. The "(R)" signifies that a response was received.

Commonwealth Department of Employment & Industrial Relations, Canberra, AUSTRALIA	L
Department of Health (Federal), Woden Act, AUSTRALIA	L
Department of Industrial Relations (New South Wales), Lidcombe, AUSTRALIA	L
Department of Mines and Energy (Northern Territory), Darwin, AUSTRALIA	L
Department of Health (Queensland), Brisbane, AUSTRALIA	L (R)
South Australia Deparment of Labour, Adelaide, AUSTRALIA	L (R)
Department of Labour and Industry (Tasmania), Hobart, AUSTRALIA	L
Department of Labour (Victoria), Melbourne, AUSTRALIA	L (R)
Commission de la santé et de la sécurité du travail du Québec, Montréal, QUÉ	L (R)
National Institute of Occupational Health, Hellerup, DENMARK	L (R)
Institute of Occupational Health, Lappeenranta, FINLAND	L (R)
Ministère du travail et de la participation, Paris, FRANCE	L
Research Institute for Environmental Health, Ministry of Health, Tel Aviv, ISRAEL	L (R)
Institut National pour la Prévention des Accidents, Rome, ITALY	L
Industrial Safety and Health Association, Tokyo, JAPAN	L (R)
National Institute of Industrial Health, Kawasaki, JAPAN	L
Health and Safety Directorate, Commission of the European Communities, LUXEMBOURG	L
Ministerie van Sociale Zaken en Werkgelengeuheid, Gravenhage, THE NETHERLANDS	L (R)
Landsorganisasjonen, Oslo, NORWAY	L
Novsk Arbeidsgizenforening, Oslo, NORWAY	L
National Board of Occupational Safety and Health, Solna, SWEDEN	L (R)
Caisse nationale Suisse d'assurance en cas d'accidents, Lucerne, SWITZERLAND	L
Health and Safety Executive, London, U.K.	L
California Department of Industrial Relations, San Francisco, U.S.A.	L (R)
Massachusetts Department of Labour & Industries, Boston, U.S.A.	L
New Jersey Department of Labour & Industries, Trenton, U.S.A.	L (R)

New York State Department of Labour, New York, U.S.A.	L (R)
Texas Department of Health, Austin, U.S.A.	L (R)
Washington Department of Labour & Industries, Olympia, U.S.A.	L (R)
Auschuss für gefährliche Arbeitstoffe, Dortmund, WEST GERMANY	L (R)
Senatskommission der Deutschen Forschungsgemeinschaft, Bonn, WEST GERMANY	L (R)

II. ESTIMATION OF QUANTITIES OF BERYLLIUM-CONTAINING MATERIALS CONSUMED IN ONTARIO

It was clearly apparent during this study that the quantities of beryllium alloys (predominantly copper-beryllium) used in Ontario far outweigh those of beryllium metal and beryllia, but we were unable to obtain direct evidence for the actual amounts involved. Statistics Canada publishes information concerning imports of these commodities for Canada as a whole, and the data for the period 1976 to 1982 (the last year for which figures were available) are presented in Table II-1. However, some of these Statistics Canada data are puzzling. Imports identified as "beryllium" (which one would normally assume to refer to beryllium metal) appear high in comparison with those identified as "beryllium alloys" (2.2 tonnes versus 4.5 tonnes, respectively, in 1982). There is also the question of unit prices: the Statistics Canada data imply that "beryllium" is only about four times more expensive than beryllium alloys — alloys which normally contain less than one or two percent beryllium. Ballance *et al.* state that the 1977 price of pure beryllium in the United States was US$265/kg [2], and McCutcheon states that the delivered price in Canada of pure beryllium was US$532/kg in 1982 [3]. In contrast, the 1982 price range given by McCutcheon for copper-beryllium alloys was US$10 to US$18/kg [3].

We have no direct information to explain these apparent price contradictions, but the unit-price figures and the import quantities from the Statistics Canada data may be rationalized if it is assumed that most of the "beryllium" category was in fact made up of copper-beryllium alloy imports incorrectly classified as beryllium. (After all, as is noted elsewhere in this report [Section 5.1.3], it is quite common in certain industrial sectors to call copper-beryllium alloys "beryllium".) If we hypothesize that such a misclassification occurred, an idea of the true quantities imported into Canada may be gained by assuming "reasonable" unit-prices for the commodities: *viz,* about C$600/kg for pure beryllium and C$18/kg for beryllium alloys (the unit-cost suggested by the Statistics Canada data for 1982). As may be seen from the calculations presented in Figure II-1, these assumptions imply that some 220 to 270 kg of beryllium would have been imported into Canada in the early 1980s. The corresponding range for beryllium alloys would be some 6.5 to 12 tonnes annually. The quantity for beryllium alloys is likely an underestimate because there are a number of copper-beryllium items which enter Canada as finished products and which

TABLE II-1 Canadian Imports of Beryllium Metal and Beryllium Alloys as Reported by Statistics Canada for the Period 1976 to 1982 [1]

YEAR	Beryllium: Primary Forms and Fabricated Materials*			Beryllium Alloys: Primary Forms and Fabricated Materials*		
	Quantity (kg)	Value (C$)	Av. value (C$/kg)†	Quantity (kg)	Value (C$)	Av. value (C$/kg)†
1976	3,934	58,000	15	12,497	161,000	13
1977	6,265	72,000	11	17,320	185,000	11
1978	1,743	172,000	99	16,428	230,000	14
1979	3,040	224,000	74	25,872	360,000	14
1980	3,606	224,000	62	8,537	155,000	18
1981	4,501	225,000	50	4,411	82,000	19
1982¶	2,192	166,000	76	4,522	83,000	18

* Statistics Canada's descriptions

† calculated from the quantity and value figures given by Statistics Canada

¶ the last year for which published figures were available

Assume the unit prices for beryllium and beryllium alloys are C$600 and C$18, respectively. Let B = kg of beryllium and C = kg of beryllium alloys imported into Canada under the "Beryllium: Primary Forms and Fabricated Materials" category. Then, using the figures presented in Table II-1:

	1982	1981	1980
{1}	$B + C = 2{,}192$	$B + C = 4{,}501$	$B + C = 3{,}606$
{2}	$600\,B + 18\,C = 166{,}000$	$600\,B + 18\,C = 225{,}000$	$600\,B + 18\,C = 224{,}000$
{3} (18 x {1})	$18\,B + 18\,C = 39{,}456$	$18\,B + 18\,C = 81{,}018$	$18\,B + 18\,C = 64{,}908$
{2} – {3}	$582\,B = 126{,}544$	$582\,B = 143{,}982$	$582\,B = 159{,}092$
	$\therefore B = 217$ kg	$\therefore B = 247$ kg	$\therefore B = 273$ kg
	and $C = 1{,}975$ kg	and $C = 4{,}254$ kg	and $C = 3{,}333$ kg
	$\therefore$ total Be alloys* = 6,497 kg	$\therefore$ total Be alloys* = 8,665 kg	$\therefore$ total Be alloys* = 11,870 kg

* C plus the quantity identified in the "Beryllium Alloys: Primary Forms and Fabricated Materials" category in Table II-1.

FIGURE II-1 Estimation of Quantities of Beryllium and Beryllium Alloys Imported into Canada Assuming Misclassification in Statistics Canada's Trade Figures

may, therefore, not be identified as being comprised of copper-beryllium — aluminum die-casting plunger tips and electrical connectors are two such examples.

If it is assumed that the consumption of beryllium-containing materials in Ontario parallels the Province's share of total Canadian manufacturing activity then an estimate of the amounts used may be made. From information published by Statistics Canada [4], it may be calculated that Ontario's share of the country's manufacturing value-added in 1982 was 52 percent. On this basis, we would estimate that 3.5 to 6 tonnes of copper-beryllium might be consumed annually in Ontario (i.e., 50 percent of the range estimated for Canada in the early 1980s). We suspect, however, that, mainly because of activities associated with Candu nuclear reactors [Section 3.1.2], Ontario would consume most of the 220 to 270 kg of pure beryllium.

REFERENCES

1. *Imports: Merchandise Trade Commodity Trade Detail 1982*, Catalogue No. 65-207. Ottawa, Ont.: Statistics Canada (1983).

2. Ballance, J., A.J. Stonehouse, R. Sweeney, and K. Walsh, "Beryllium and beryllium alloys", in *Kirk-Othmer Encyclopedia of Chemical Technology*, 3rd Edition, Volume 3, pp. 803-823. Toronto, Ont.: John Wiley & Sons (1978).

3. McCutcheon, W., "Beryllium", *Canadian Minerals Yearbook 1982*, pp. 7.1-7.4. Ottawa, Ont.: Energy, Mines and Resources (1982).

4. *Manufacturing Industries of Canada: National and Provincial Areas 1982*, Catalogue No. 31-203, Tables 1 and 29. Ottawa, Ont.: Statistics Canada (1984).

III. INDUSTRY SURVEY

The survey of industrial users of beryllium-containing materials formed the backbone of the whole study. It comprised three consecutive phases, and each one enabled the gathering of progressively more detailed information as more familiarity with the topics was gained. The first phase, a simple mail-out questionnaire, was designed: 1) to identify the types of beryllium-containing materials used, 2) to gather information on activities in which such materials are involved, and 3) to gain an idea of the numbers of workers who may be handling the materials in Ontario. The information obtained was expanded upon by in-depth follow-up telephone interviews with a majority of those respondents who indicated that beryllium-containing materials were used in their operations. The survey concluded with plant visits of a representative cross section of beryllium-material users. Each visit included a walk-through survey of the work areas.

III.1 MAIL-OUT QUESTIONNAIRE

At the start of the project, we had only a very general idea of the type of industry in which beryllium-containing materials were used. This idea had been gained from reviews on the topic (e.g., Ballance *et al.* [1], EPA [2], OSHA [3]) and from information provided by the Ministry of Labour — an information sheet on beryllium for use by its inspectors [4] and a list of 28 companies which deserved to be contacted during the study [5] (both these pieces of information were supplied with the Request for Proposal). And it was from this information base that the design of the mail-out questionnaire survey was started.

III.1.1 Sample Selection

We felt it reasonable to assume that the 28 companies identified by the Ministry were likely to be users of beryllium-containing materials. These companies were therefore used as a guide for selecting additional establishments for inclusion in the questionnaire survey.

The 28 companies embrace 40 different Standard Industrial Classification (SIC) categories [Table III-1]. Even allowing for duplication (many companies are listed under more than one SIC), there are many thousands of companies in Ontario represented by these categories [6]. The most rigorous approach to sample selection would have been to

TABLE III-1 SIC Classifications Represented by the 28 Companies Identified by the Ministry of Labour*

SIC†	Description†
CHEMICALS AND ALLIED PRODUCTS	
2819	Industrial inorganic chemicals (n.e.c.)
RUBBER AND MISCELLANEOUS PLASTIC PRODUCTS	
3079	Miscellaneous plastic products
PRIMARY METAL INDUSTRIES	
3356	Rolling, drawing and extruding of nonferrous metals (ex. Al and Cu)
3361	Aluminum foundries (castings)
3362	Brass, bronze, copper, copper base alloy foundries (castings)
3369	Nonferrous foundries (castings) (n.e.c.)
FABRICATED METAL PRODUCTS (except machinery and transportation equipment)	
3443	Fabricated plate work (boiler shops)
3444	Sheet metal work
3451	Screw machine products
3452	Bolts, nuts, screws, rivets and washers
3469	Metal stampings (n.e.c.)
3499	Fabricated metal products (n.e.c.)
MACHINERY (except electrical)	
3511	Steam, gas and hydraulic turbines, and turbine generator units
3519	Internal combustion engines (n.e.c.)
3544	Special dies and tools, die sets, jigs, industrial moulds
3545	Machine-tool accessories and measuring devices
3549	Metalworking machinery (n.e.c.)
3559	Special industry machinery (n.e.c.)
3567	Industrial process furnaces and ovens
3569	General industrial machinery and equipment (n.e.c.)
3573	Electronic computing equipment
3585	HVAC equipment, commercial and industrial refrigeration equipment
3599	Miscellaneous machine-shop work
ELECTRICAL AND ELECTRONIC MACHINERY, EQUIPMENT AND SUPPLIES	
3613	Switchgear and switchboard apparatus
3621	Motors and generators
3623	Welding apparatus (electric)
3629	Electrical industrial apparatus (n.e.c.)
3632	Household refrigerators, and home and farm freezers
3634	Electric housewares and fans
3639	Household appliances (n.e.c.)
3643	Current-carrying wiring devices
3662	Radio and television transmitting, signaling and detection equipment
3679	Electronic components (n.e.c.)
TRANSPORTATION EQUIPMENT	
3728	Aircraft parts and auxiliary equipment (n.e.c.)
3769	Guided missile and space vehicle parts (n.e.c.)
MEASURING, ANALYZING AND CONTROL INSTRUMENTS, PHOTOGRAPHIC, MEDICAL AND OPTICAL GOODS, WATCHES AND CLOCKS	
3811	Engineering, laboratory, scientific and research instruments
3822	Automatic controls for regulating residential and commercial environments
3823	Industrial instruments for measurement and control of process variables
3841	Surgical and medical instruments and apparatus
3861	Photographic equipment and supplies

* List of 28 companies identified by the Ministry of Labour in their Request for Proposal [5]

† Classification numbers and definitions from *Scott's Directory of Ontario Manufacturers* [6]

n.e.c. not elsewhere classified

take a random sample, stratified according to company size, from each of the 40 SIC categories in a similar manner to the approach successfully used by Holliday *et al.* in an earlier project [reference 7, Appendix III]. But while such an approach has the potential to provide statistically significant results, we felt that it might cause a problem in the case of beryllium-containing materials. Canadian trade figures show that the quantities of beryllium metal and beryllium alloys imported into the country are very small — 6.7 tonnes with a total value of $249,000 in 1982 (the latest figures available) [Table II-1 in this report and reference 8] — amounts which, if distributed equally among all the companies in Ontario represented by the 40 SIC categories in Table III-1, would result in each establishment receiving 0.5 to 1 kg per year. Clearly, the use of such materials must be limited to a comparatively few companies. With the resources available to the project — the contract called for a mail-out questionnaire to be sent to "about 100 establishments" — there was a danger that random sample selection would have yielded so few potential "hits" that no meaningful information would have been obtained from the responses.

We decided, instead, to use a directed-sampling approach. To this end, some 16 trade associations, trade unions, and professional associations were initially approached to gain information on companies which might be using beryllium-containing materials (these organizations are among those listed in Appendix I). Some associations provided lists of particular groups within their membership, but were often unable to indicate which companies were likely to use beryllium-containing materials. Similarly, trade union representatives were, in most instances, only able to provide guesses as to which companies (among those in which they had members) might be using such materials. Specialized metal suppliers and companies in the metal fabricating trades were also contacted for information on specific aspects of the use of beryllium-containing materials. These contacts had a good idea as to which industry groups were using these materials and, in some cases, were able to indicate which firms and establishments were likely to be good prospects for the survey. Our final approach was to identify companies from industrial trade directories based on the information gleaned from published literature and conversations with industry representatives and, it should be admitted, on intuition. The directories consulted were: *Scott's Directory of Ontario Manufacturers* [6], *Fraser's Canadian Trade Directory* [9], *Make it in Ontario: Non-Ferrous and Ferrous Foundry Jobbing Capabilities* [10], and *Die-Casting in Canada: Manual and Directory* [11].

This exercise resulted in the selection of a survey sample consisting of 172 establishments from 156 different companies. These companies, which included the 28 originally identified by the Ministry, are listed in Appendix I. The majority of the establishments could be classified in 10 different manufacturing-industry groups, and the remaining few were placed in a "miscellaneous" group [Table III-2]. This *a priori* classification served as the starting point for analysis of the survey response [Sections III.1.4 and III.3.1].

III.1.2 Questionnaire Development

Our aim was to produce a short, easily answered questionnaire which elicited such basic information as: classes of beryllium-containing materials used, the types of manufacturing activities in which the materials were involved, the products produced, and the number of workers who might be handling the beryllium-containing materials. More detailed information on such pertinent matters as exposure-control measures would be obtained from follow-up telephone interviews with respondents who indicated that beryllium-containing materials were used in their operations.

The questionnaire was developed concurrently with the selection of the survey sample. It was compiled from information gleaned from published material and from talking with industry representatives. Input was also sought from Ministry of Labour personnel. Draft versions of the questionnaire were pre-tested by telephone on a few selected companies. This pre-test indicated some slight modifications which would yield an improved questionnaire. The final version of the questionnaire [Figure III-1] was submitted to the Ministry of Labour for approval before it was mailed.

III.1.3 Administration of the Survey

A letter from the Minister explaining the purpose of the study and requesting co-operation [Figure III-2] was mailed by the Ministry of Labour to all survey recipients on 25 July 1986, one week before the questionnaire was mailed out. It has been our experience that such a practice improves survey response. The questionnaire package, consisting of an introductory letter from ourselves [Figure III-3], the questionnaire [Figure III-1] and a reply-paid return envelope, was mailed on 31 July 1986. Response was excellent (see next

TABLE III-2 Original Survey Classification

Original Classification	Description
AUTOMOBILE MANUFACTURE	The "big three" automobile manufacturers
AVIONICS	Manufacturers of aircraft, avionics parts, and spacecraft-related hardware
BEARINGS & BUSHINGS	Bearing manufacturers and screw-machine shops
DIE CASTINGS	Ontario aluminum die casters identified in *Die Casting in Canada: Manual & Directory* [11]
ELECTRCAL CONTACTS	Manufacturers of electrical contacts, connectors and switchgear
FOUNDRIES	All non-ferrous foundries identified in the *Make It in Ontario: Non-Ferrous and Ferrous Foundry Jobbing Capabilities* [10] as casting copper-beryllium
HOUSEHOLD APPLIANCES	A selection of Ontario establishments manufacturing major household appliances
MOULDS/TOOL MAKING	A selection of tool & die makers and machine shops specializing in making moulds for plastic blow-moulding
SOLID STATE	A selection of electronics companies involved in the high-technology field
SPRINGS	A selection of manufacturers of springs and related items
MISCELLANEOUS	A variety of companies including some associated with the nuclear industry, medical equipment manufacture, resistance welding, etc.

BERYLLIUM INDUSTRIAL USE QUESTIONNAIRE

1. Does your plant use beryllium compounds or alloys in any form? [Includes beryllium metal, copper-beryllium and other beryllium alloys, beryllia (beryllium oxide), or parts containing these substances.] *If YES, please go to Question 3.* YES ☐ NO ☐

2. Has your plant used beryllium compounds or alloys in the past five years? If yes, please explain why you stopped using these materials and what substitutes you now use. YES ☐ NO ☐

____

____

If YES, then please complete the questionnaire as if you were still using beryllium compounds.
If NO to both Questions 1 and 2, please stop and return the questionnaire.

3. What particular form of beryllium compounds or alloys do you use?

☐ Beryllium metal
☐ Copper-beryllium alloy
☐ Aluminum-beryllium alloy
☐ Nickel-beryllium alloy
☐ Beryllia
☐ Parts containing beryllium
☐ Other (please specify)
____
____

4. How is the beryllium compound or alloy processed or used?

a) As a raw material:
☐ laser cutting/trimming
☐ cutting/slitting/shearing
☐ stamping/forming of parts
☐ tumbling/deburring
☐ casting/forging
☐ machining
☐ grinding
☐ welding
☐ none of the above

b) As a fabricated material
☐ assembly of parts containing beryllium compounds or alloys
☐ maintenance of equipment containing beryllium compounds or alloys
☐ none of the above

c) As a tool component:
☐ spot-welding tips
☐ die-casting plunger tips
☐ moulds for plastic
☐ bearings/bushings in machine tools
☐ none of the above

d) Do you process or use beryllium compounds or alloys in any other ways? NO ☐

☐ YES (please specify) ______________________________
____

5. What products does your plant produce? ______________________________
____

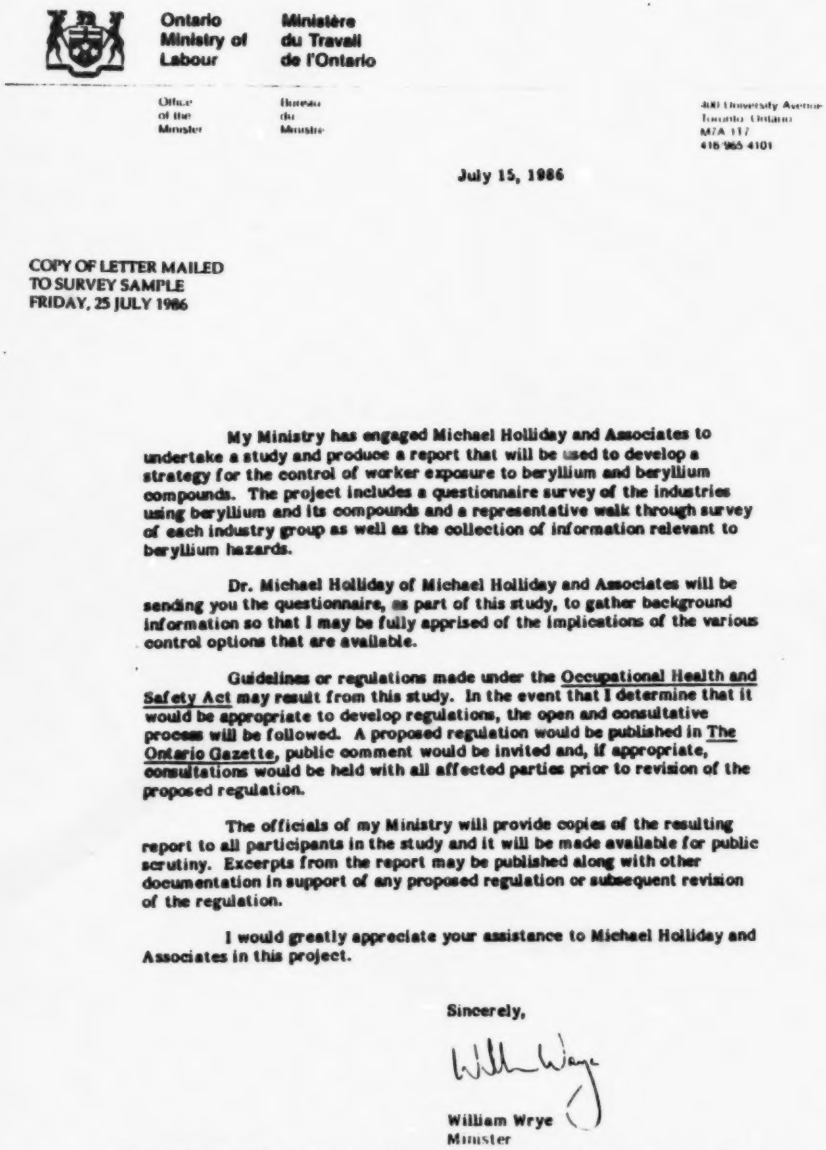
6. Which of these products contain beryllium compounds or alloys? ______________________________
____

7. How many production workers were employed in your plant on a regular basis during the peak employment periods in 1985? ______________

8. How many production workers in your plant handled beryllium compounds or alloys on a regular basis during peak employment periods in 1985? ______________

WE VERY MUCH APPRECIATE YOUR TROUBLE IN COMPLETING THIS QUESTIONNAIRE AND THANK YOU FOR YOUR ASSISTANCE. PLEASE USE THE ADDRESSED, POSTAGE PRE-PAID ENVELOPE TO RETURN THE QUESTIONNAIRE TO MICHAEL HOLLIDAY & ASSOCIATES.

FIGURE III-1 Mail-Out Survey Questionnaire [actual size 8 1/2" x 14"]



Ontario
Ministry of
Labour

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du Travail
de l'Ontario

Office
of the
Minister

Bureau
du
Ministre

400 University Avenue
Toronto Ontario
M7A 1T7
416 965 4101

July 15, 1986

COPY OF LETTER MAILED
TO SURVEY SAMPLE
FRIDAY, 25 JULY 1986

My Ministry has engaged Michael Holliday and Associates to undertake a study and produce a report that will be used to develop a strategy for the control of worker exposure to beryllium and beryllium compounds. The project includes a questionnaire survey of the industries using beryllium and its compounds and a representative walk through survey of each industry group as well as the collection of information relevant to beryllium hazards.

Dr. Michael Holliday of Michael Holliday and Associates will be sending you the questionnaire, as part of this study, to gather background information so that I may be fully apprised of the implications of the various control options that are available.

Guidelines or regulations made under the Occupational Health and Safety Act may result from this study. In the event that I determine that it would be appropriate to develop regulations, the open and consultative process will be followed. A proposed regulation would be published in The Ontario Gazette, public comment would be invited and, if appropriate, consultations would be held with all affected parties prior to revision of the proposed regulation.

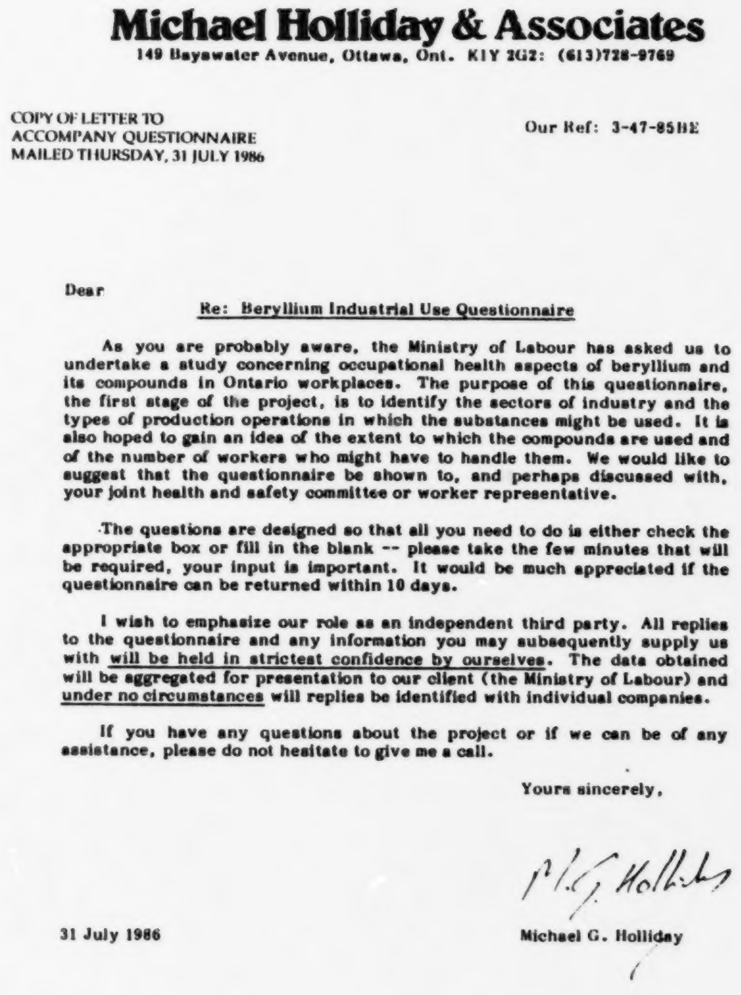
The officials of my Ministry will provide copies of the resulting report to all participants in the study and it will be made available for public scrutiny. Excerpts from the report may be published along with other documentation in support of any proposed regulation or subsequent revision of the regulation.

I would greatly appreciate your assistance to Michael Holliday and Associates in this project.

Sincerely,

William Wrye
Minister

FIGURE III-2 Introductory Letter from the Ministry of Labour [actual size 8 1/2" x 11"]



Michael Holliday & Associates
149 Bayswater Avenue, Ottawa, Ont. K1Y 2G2: (613)728-9769

COPY OF LETTER TO
ACCOMPANY QUESTIONNAIRE
MAILED THURSDAY, 31 JULY 1986

Our Ref: 3-47-85BE

Dear

Re: Beryllium Industrial Use Questionnaire

As you are probably aware, the Ministry of Labour has asked us to undertake a study concerning occupational health aspects of beryllium and its compounds in Ontario workplaces. The purpose of this questionnaire, the first stage of the project, is to identify the sectors of industry and the types of production operations in which the substances might be used. It is also hoped to gain an idea of the extent to which the compounds are used and of the number of workers who might have to handle them. We would like to suggest that the questionnaire be shown to, and perhaps discussed with, your joint health and safety committee or worker representative.

The questions are designed so that all you need to do is either check the appropriate box or fill in the blank -- please take the few minutes that will be required, your input is important. It would be much appreciated if the questionnaire can be returned within 10 days.

I wish to emphasize our role as an independent third party. All replies to the questionnaire and any information you may subsequently supply us with will be held in strictest confidence by ourselves. The data obtained will be aggregated for presentation to our client (the Ministry of Labour) and under no circumstances will replies be identified with individual companies.

If you have any questions about the project or if we can be of any assistance, please do not hesitate to give me a call.

Yours sincerely,

M. G. Holliday

31 July 1986

Michael G. Holliday

FIGURE III-3 Introductory Letter Sent with the Questionnaire [actual size 8 1/2" x 11"]

section), but a couple of industry groups were under-represented. A reminder letter was sent to non-respondents (16 in all) in these groups on 9 October 1986.

III.1.4 Survey Response

Although the second week after the questionnaire was mailed saw the highest response rate (implying that a significant fraction of respondents — actually 28 percent — essentially replied by return mail), replies were quite slow in coming in [Figure III-4]. It is probable that the major reason for this atypical response pattern was because the questionnaire package was sent at a time when a number of companies were starting their annual summer shutdown. Over 60 percent of responses, however, had been received within a month of the mail-out. The reminder letter appeared successful in bringing in recalcitrant responses (11 responses from 16 reminder letters sent out — the other three responses in this period were from companies not sent a reminder).

A few companies receiving the questionnaire had more than one plant in which beryllium-containing materials were employed and some of these companies sent more than one completed questionnaire — hence the "179 establishments surveyed" in Table III-3, compared with the 172 questionnaires sent out. As seen from Table III-3, an overall response of 74 percent was achieved; the response from the individual industry groups (named as "original classification" in the table) varied from a low of 62 percent to 100 percent. Just over 60 percent of the respondents reported that beryllium-containing materials were used in some way in their operations. But there was considerable variation in beryllium-material use among the different industry groups; from essentially zero in the "bearings & bushings" classification (the only positive respondent in this category turned out to have been mis-classified) to 100 percent among the "big three" automakers.

III.2 TELEPHONE FOLLOW-UP INTERVIEWS AND PLANT VISITS

As already mentioned, the mail-out questionnaire was designed to provide basic information. Detailed information concerning activities in which beryllium-containing materials were used, the exposure controls (both engineering and work-practice), and exposure monitoring were obtained from follow-up telephone interviews. A telephone-

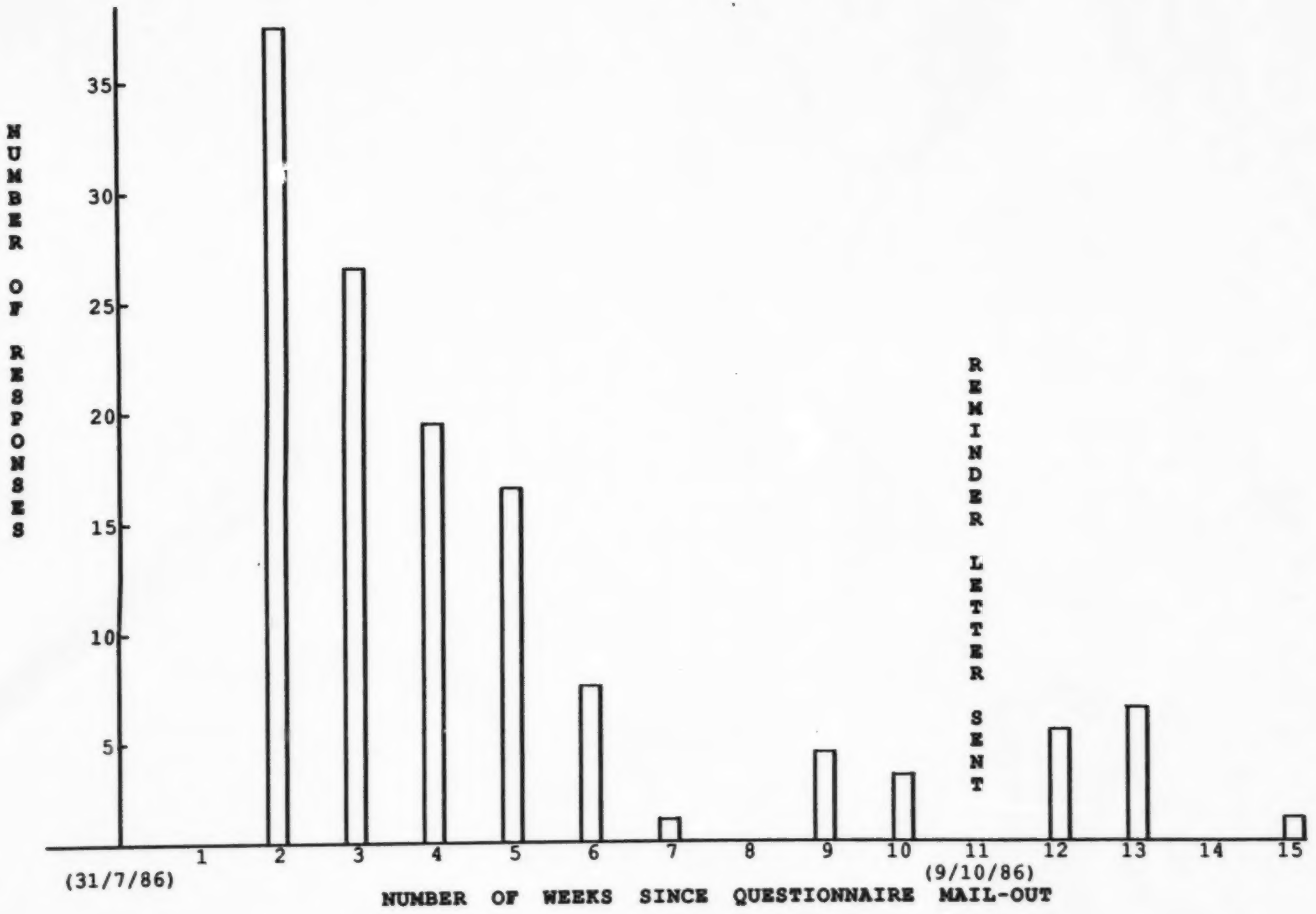


FIGURE III-4 Response to Mail-Out Questionnaire

TABLE III-3 Questionnaire Response and Use of Beryllium-Containing Materials

Original Classification	# Establishments Surveyed	# Responding (% response)		# Using Be-Materials (% of respondents)*	
AUTOMOBILE MANUFACTURE	3	3	(100%)	3	(100%)
AVIONICS	7	7	(100%)	5	(71%)
BEARINGS & BUSHINGS	9	7	(78%)	†1	(14%)
DIE CASTINGS	29	20	(69%)	16	(80%)
ELECTRICAL CONTACTS	35	23	(66%)	9	(39%)
FOUNDRIES	8	6	(75%)	4	(67%)
HOUSEHOLD APPLIANCES	8	5	(63%)	2	(40%)
MOULDS/TOOL MAKING	25	20	(80%)	12	(60%)
SOLID STATE	15	13	(87%)	¶7	(54%)
SPRINGS	19	16	(84%)	13	(81%)
MISCELLANEOUS	21	13	(62%)	9	(69%)
TOTALS	179	133	(74%)	81	(61%)

* Includes four companies who reported using beryllium-containing materials, but who do not currently do so.

† This company, as it turned out, was mis-classified and did not produce bearings or bushings.

¶ Only one of these seven companies used beryllia, the rest only used copper-beryllium.

interview *pro forma* was devised [Appendix IV] as a guide for the interviewers (interviewing was carried out by the authors of this report). Sixty-five percent of respondents who had indicated use of beryllium-containing materials were interviewed [Table III-4]. In most industry groupings about three quarters of these respondents were interviewed, but in a couple of groups it was found that information supplied by the interviewers varied so little from establishment to establishment that such complete coverage was not necessary. Interviews were conducted during October and November 1986.

A representative cross section of the establishments interviewed were visited [Table III-4] as the final phase of information gathering. In addition to walk-through surveys of the areas where beryllium-containing materials were used, discussions were conducted with both labour and management representatives about their opinions and perceptions concerning the use of beryllium-containing materials in the workplace. The visits took place during November and December 1986, and the first part of January 1987.

The considerable amount of information gained from the telephone interviews and plant visits forms the basis for Chapters 3, 4 and 5. It will not be re-summarized here.

III.3 RESULTS FROM THE MAIL-OUT QUESTIONNAIRE RESPONSES

For the reasons outlined in Section III.1.1, it is not possible to say whether the sample selected was a proportionate representation of the "population" using beryllium-containing materials in Ontario (in fact, it is likely that it is not), and differential responses for the individual industry groups may add additional (and also unquantifiable) biases. Furthermore, individuals delegated by their companies to complete the questionnaire were not always well informed about all the uses of beryllium-containing materials in their plants. (For instance, the industrial hygienist at a large company's head office was acquainted with the use of copper-beryllium resistance-welding electrodes at the main plant, but proved to be unaware of the use of copper-beryllium plunger tips in the company's aluminum die-casting plant located in another city.) Telephone interviews confirmed that erroneous responses were given in some of the mail-out questionnaires. Finally there is enormous variation in the frequency of use of beryllium-containing materials by responding establishments. Virtually every aluminum die-casting plant, for example, uses and

TABLE III-4 Follow-up Telephone Interviews and Plant Visits

Industry Classification[§]	# Establishments Reporting Be-Material Use	# Establishments Involved in Follow-up Interviews[*]	# Plant Visits [†]
PRECISION MACHINING	3	3	1
NUCLEAR APPLICATIONS	4	2	1
MICROCIRCUITS	1	1	1
CASTING/FORGING	6	4	2
MACHINING	15	12	2
STAMPING/CUTTING	20	11	2
DIE CASTING	12	4	1
PLASTIC MOULDING	4	3	0
RESISTANCE WELDING	6	5	1
HANDLING/ASSEMBLY	10	8	0
TOTALS	81	53	[¶]11

[§] This classification corresponds to the reclassification of the original *a priori* classification in light of information gained during the interviews and visits [Section III.3.1].

[*] In a number of cases, more than one telephone interview was necessary to obtain all the relevant information.

[†] Walk-through surveys were conducted at every plant visited.

[¶] One additional visit was made to a microcircuit manufacturer (who did not use beryllia) during the questionnaire development phase of the project.

machines copper-beryllium plunger tips on a daily basis, while some machine shops and foundries may only use copper-beryllium once every one or two years.

The data presented below cannot, therefore, be used to draw inferential conclusions about the whole population because the sample was not truly representative, the responses were not of uniform quality, and there was a wide variation in the frequency of use of beryllium-containing materials. The questionnaire results are, however, representative of the sample chosen, and may well be a reasonable representation of the "population" as a whole.

With these caveats in mind, we feel that the questionnaire results presented in the sections which follow can be taken as a valid guide to processes using beryllium-containing materials in Ontario industry. And nothing observed during plant visits or told us during telephone interviews contradicted this supposition.

III.3.1 Re-classification of Industry Grouping

The establishments surveyed were selected according to an *a priori* classification based on an industrial grouping of establishments which produce similar products [Section III.1.1 and Table III-2]. However, analysis of completed questionnaires and the follow-up telephone interviews showed that this *a priori* classification did not lend itself easily to a discussion of the situation from an occupational-health viewpoint. It was found, for example, that plants employing similar process techniques and the same beryllium-containing materials fell into different industry groups. Conversely, within the same group could be found establishments using quite different processing techniques and different beryllium-containing materials, and thus posing different exposure potentials. Consequently, a new classification was devised to reflect similarities of raw materials and manufacturing processes [Table III-5]. By discriminating between processes and materials this "new" classification combines establishments into groups with a similar potential for beryllium exposure. The relationship between the old (*a priori*) classification and the new classification is shown in Table III-6.

TABLE III-5 New Industry Classification

New Classification*	Description
PRECISION MACHINING	Precision machining and/or assembly of pure beryllium parts
NUCLEAR APPLICATIONS	Companies associated with nuclear energy which use pure beryllium or beryllium containing parts
MICROCIRCUITS	Manufacturers of electronic microcircuits which use beryllia
CASTING/FORGING	Foundries which cast and/or forge beryllium alloys
MACHINING	Companies involved in machining copper-beryllium; includes mould manufacturers and manufacturers of resistance welding electrodes
STAMPING/CUTTING	Companies involved in stamping, cutting, and slitting of copper-beryllium: includes spring, contact, and electrical-connector manufacturers
DIE CASTING	Companies involved in producing aluminum and magnesium-alloy die castings
PLASTIC MOULDING	Companies producing plastic products by blow- and injection-moulding using moulds containing copper-beryllium, but who do not make their own moulds.
RESISTANCE WELDING	Companies which use resistance welding to produce their products: automobile manufacturers, household appliance manufacturers
HANDLING/ASSEMBLY	Companies which handle copper-beryllium items (e.g., metal distributors) or who solely assemble products containing copper-beryllium parts

* Based only on questionnaire respondents who reported using beryllium-containing materials.

TABLE III-6 Concordance Between Number of Respondents in Original Survey Classification and the Classification Devised from Analysis of Survey Replies

		NEW CLASSIFICATION									
ORIGINAL CLASSIFICATION	ROW TOTALS	Precision Machining	Nuclear Applications	Micro-Circuits	Casting/ Forging	Mach-ining	Stamping /Cutting	Die Casting	Plastic Moulding	Resistance Welding	Handling/ Assembly
Automobile	3	--	--	--	--	--	--	--	--	3	--
Avionics	5	2	--	--	--	2	--	--	--	--	1
Bearings	1	--	--	--	--	--	1	--	--	--	--
Die Casting	16	--	--	--	2	1	--	12	--	--	1
Electric Contacts	9	--	--	--	--	1	6	--	--	--	2
Foundries	4	--	--	--	4	--	--	--	--	--	--
Household Appliances	2	--	--	--	--	--	--	--	--	2	--
Moulds/Tool Making	12	--	--	--	--	8	--	--	4	--	--
Solid State	7	1	--	1	--	1	2	--	--	--	2
Springs	13	--	--	--	--	--	10	--	--	1	2
Miscellaneous	9	--	4	--	--	2	1	--	--	--	2
COLUMN TOTALS	81	3	4	1	6	15	20	12	4	6	10
		Beryllium Use		BeO Use	Be Alloy Use			Be Alloy Used as Tool Component			Assembly

III.3.2 Use of Beryllium-Containing Materials

Table III-7 summarizes responses with regard to the use of beryllium-containing materials among survey respondents.* Clearly, copper-beryllium alloy is by far the most commonly used beryllium-containing material (89 percent of respondents). Pure beryllium use (8 percent of respondents) is confined exclusively to those few companies either in high-precision fabrication for defence-related purposes and space satellites, or in manufacturing activities related to nuclear reactors. Beryllia appears to be scarcely used (only 2 percent of respondents); the only two respondents reporting such use are "high-technology" companies.

III.3.3 Activities Involving Beryllium-Containing Materials

An idea of how beryllium-containing materials are used within the industry groups may be gained from Table III-8. Over 40 percent of respondents mentioned carrying out assembly operations involving the materials and this was the activity most commonly reported — inevitably, perhaps, as many companies both fabricated components from beryllium-containing material and used them in the assembly of finished products. But of greater import from an occupational-health standpoint are activities carried out on beryllium-containing material.

Machining is the most common operation and was reported by 35 percent of respondents. In addition to its virtually universal use in the machining and fabrication category, machining is reported quite extensively in the casting/forging, die-casting, and precision-machining categories; in this latter category it is beryllium metal that is being machined. The next most common operations are stamping (22 percent of respondents) and cutting/shearing (11 percent) and, as expected, these activities predominate in the stamping/cutting industry category. Some stamping/cutting operations are also carried out in establishments belonging to the machining and fabrication category. Casting of beryllium alloys was reported by 7 percent of respondents.

---

* In the tables and the discussion in the text, it should be remembered that percentages refer only to the respondents who reported using beryllium-containing materials (i.e., 61 percent of those responding to the survey).

TABLE III-7 Use of Beryllium-Containing Materials: By Industry Classification

Industry Classification	Number of Respondents	Percentage of Respondents Within Each Classification Using Beryllium Compounds					Percentage of Workforce Within Each Classification Handling Beryllium Compounds
		Be	BeO	Cu/Be	Al/Be	Other	
BERYLLIUM METAL							
Precision machining	3[†]	100	33	--	--	--	0.5
Nuclear applications	4	75	--	25	--	25	1.2
BERYLLIA							
Microcircuits	1	--	100	--	--	--	100
BERYLLIUM ALLOYS							
Casting/forging	6	--	--	67	17	17	33
Machining	15[†]	--	--	100	--	--	3.9
Stamping/cutting	20[¶]	--	--	100	--	--	16
Die casting	12	--	--	100	--	--	6.8
Plastic moulding	4	--	--	100	--	--	2.1
Resistance welding	6	--	--	100	--	--	8.6
Handling/assembly	10	--	--	90	--	10	5.2
TOTALS	81[§]	8%	3%	89%	1%	4%	7.8%

[†] Includes one respondent who used beryllium or beryllium alloys within the last 5 years but does not now.

[¶] Includes two respondents who no longer use copper-beryllium, but who did use it within the last 5 years.

[§] Includes the four respondents who no longer use beryllium or its alloys.

TABLE III-8 Activities and Operations Involving Beryllium-Containing Materials: By Industry Classification

	INDUSTRY CLASSIFICATION										
	Precision Machining	Nuclear Applications	Micro-circuits	Casting/ Forging	Machining	Stamping/ Cutting	Die Casting	Plastic Moulding	Resistance Welding	Handling/ Assembly	TOTALS
NUMBER OF RESPONDENTS*	3	4	1	6	15	20	12	4	6	10	81
PERCENT OF RESPONDENTS USING:											
Beryllium metal	100%	75%	--	--	--	--	--	--	--	--	7%
Beryllia	33%	--	100%	--	--	--	--	--	--	--	2%
Beryllium alloys	--	50%	--	100%	100%	100%	100%	100%	100%	100%	93%
OPERATIONS DIRECTLY ON BERYLLIUM COMPOUND†											
Laser cutting	--	--	100%¶	--	--	--	--	--	--	--	1%
Cutting and shearing	--	25%	--	17%	20%	20%	--	--	--	--	11%
Stamping	--	--	--	--	7%	85%	--	--	--	--	22%
Tumbling/deburring	--	--	--	17%	--	--	--	--	--	--	1%
Casting/forging	33%	--	--	83%	--	--	--	--	--	--	7%
Machining	67%	--	--	50%	93%	5%	50%	25%	17%	--	35%
Grinding	33%	--	--	33%	20%	5%	--	--	--	--	9%
Welding	--	50%	--	--	--	10%	--	--	--	--	5%
BERYLLIUM COMPOUND USED AS TOOL COMPONENT†											
Welding electrodes	--	--	--	--	--	--	--	--	100%	--	7%
Plunger tips	--	--	--	--	--	--	100%	--	17%	--	16%
Plastic moulds	--	--	--	--	33%	--	--	100%	17%	10%	15%
OTHER OPERATIONS INVOLVING BERYLLIUM COMPOUNDS†											
Assembly of parts	67%	75%	100%	17%	40%	40%	--	25%	33%	90%	41%
Maintenance	--	--	--	--	7%	5%	100%	--	100%	10%	26%
Non-specific	--	25%	100%	--	13%	--	--	--	--	--	5%

---

* Includes 4 companies who used beryllium compounds within the last 5 years, but who no longer use them.

† Expressed as a percentage of respondents within the indicated industry classification.

¶ The company does not now laser cut beryllia, but expects to do so in the future.

Copper-beryllium was reported as being used as a tool component by 27 percent of respondents — as resistance welding electrodes, plunger tips in die-casting machines, and in moulds used for blow- and injection-moulding of plastics. In each of these three uses, however, certain machining operations on the copper-beryllium component are routinely required — refurbishing die-casting plunger tips, refacing resistance welding electrodes, and repairing blow moulds.

III.3.4 Number of Workers "Exposed" to Beryllium-Containing Material

It is very difficult to estimate the number of workers "exposed" to beryllium because processing activities involving beryllium-containing materials are diffused throughout the manufacturing sector. Statistics Canada's Census of Manufacturers data on employment [12] are not useful in this regard because only a tiny and unknown fraction of the workers in some 40 different industries (see discussion at beginning of Section III.1) are "exposed" in some way to beryllium compounds and alloys.

The questionnaire data [Table III-9] reveal a total of about 80,000 workers in the establishments which acknowledged using beryllium-containing materials on a regular basis. Of the 80,000, some 7.8 percent (or 6,200) were reported as handling beryllium-containing materials on a regular basis. Over 80 percent of the workers handling such materials fell into the resistance-welding category; indeed, 58 percent of the total number were employed by a single firm in the automobile industry! This particular firm's respondent may have used an overly generous interpretation of "handling beryllium on a regular basis" (Question 8 in the mail-out questionnaire). While there appears to be an over-estimate in the number of workers handling beryllium-containing materials within the resistance welding group, in terms of the number of establishments surveyed this same group is probably the most under-represented of the entire survey sample. There are hundreds of establishments in the metal fabrication, transportation equipment, electrical equipment, and machinery industries which do resistance welding and may use copper-beryllium electrodes.

The 80,000 workers in the beryllium-material-using firms responding to the mail-out questionnaire survey represent about 13 percent of the 600,000 workers [12] in Ontario's manufacturing labour force. If the survey sample were a "random sample" of all manufac-

TABLE III-9 Number of Workers Reported as Handling Beryllium-Containing Materials: by Industry Classification

Industry Classification	Number of Respondents* (% of total)	Total Number of Workers in Industry Classification†	Number of Workers Handling Beryllium Compounds†	% of Workforce Within Each Classification Handling Beryllium Compound
BERYLLIUM METAL				
Precision machining	3 (4%)	1,382	7	0.5%
Nuclear applications	4 (5%)	5,342	64	1.2%
BERYLLIA				
Microcircuits	1 (1%)	17	17	100%
BERYLLIUM ALLOYS				
Casting/forging	6 (7%)	424	138	33%
Machining	15 (19%)	4,447	174	3.9%
Stamping/cutting	20 (25%)	2,213	354	16%
Die casting	12 (15%)	1,789	122	6.8%
Plastic moulding	4 (5%)	435	9	2.1%
Resistance welding	6 (7%)	58,809	5,049	8.6%
Handling/assembly	10 (12)	4,754	247	5.2%
TOTALS	81 (100%)	79,612	6,181	7.8%

* Includes the 4 companies which no longer use beryllium-containing materials, but which used them in the last 5 years

† numbers as reported by the respondents

turing companies in Ontario, then it would be expected that 7.8 percent (from Table III-9) of the manufacturing labour force (i.e., 47,000) could be taken as a conservative upper bound for the numbers of workers handling beryllium-containing materials. But the sample was not random, it was chosen very deliberately to achieve a high proportion of positive responses.

If, instead of taking the whole manufacturing sector in Ontario, we consider only those manufacturing-industry groups in which there is even the remotest possibility that workers might be handling beryllium-containing materials, then the "total" labour force drops to about 172,000 [column B in Table III-10].

In order to estimate the number of workers handling beryllium-containing materials, a series of sector-specific weights was assigned to the total numbers of workers in column B of Table III-10. The weights assigned each industry sector were based on the mail-out questionnaire results. The assignment was comparatively arbitrary in a number of instances because some of the sectors with a "remote chance" of using beryllium-containing materials were not broken out separately by Statistics Canada. As an example of the problem, we had to assign the same weighting values to the large machinery industry sector (SC 31)* as was obtained, from the survey, for the major appliance manufacturing sector (SC 332). The total employment for each sector (column B of Table III-10) was multiplied by the percentage of respondents who reported using beryllium-containing materials [Table III-3] and the percentage of the respondents' workforce reported as handling such materials [Table III-9]. The end result provides an estimate of the total number of workers handling these materials in Ontario (last column in Table III-10).

The provincial total of about 5700 workers should be considered a conservative upper bound. This is because the use of beryllium-containing materials would not be distributed among the industry sectors in the same proportions as was found in our directed sample — a sample deliberately chosen to maximize the number of hits. For this reason, a realistic lower bound would be about 30 percent less than this maximum or about 4000 workers.

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* Please note that "SC" refers to Statistics Canada industry classification and should not be confused with "SIC", the internationally used standard industrial classification.

TABLE III-10 Employment in Ontario Industries Even Remotely Likely to Use Beryllium-Containing Materials and Estimates of the Numbers of Workers Handling Such Materials

	Statistics Canada Data [12]*			Questionnaire Survey Data [Tables III-3 & III-7]		
Industry Sector (SC in brackets)	No. of Plants (A)	Industrial Workforce (B)	Average No. of Workers per Plant (B ÷ A)	Plants Using Be / Plants Responding (C)	Percent of Workforce Handling Be (D)	Estimated No. of Workers Handling Be (B x C x D)/100
PLASTIC FABRICATING (165)	454	15,289	34	12/20†	2.1	193
Al ROLLING, CASTING, ETC. (296)	39	2,938	75	16/20	6.8	160
Cu & Cu ALLOY CASTING, ETC. (297)	28	(1,977)¶	71	4/6	33	435
MACHINERY (31)	875	35,344	40	2/5†	1.0†	141
AIRCRAFT & PARTS MFR. (321)	51	7,869	154	5/7	1.0	56
MOTOR VEHICLE MFR. (323)	10	27,192	2,719	3/3	8.6	2,339
MAJOR APPLIANCE MFR. (332)	25	4,450	178	2/5	1.0	18
COMMUNICATIONS EQUIPMENT MFR. (335)	263	18,513	70	7/13†	4.0†	399
ELECTRICAL INDUSTRY EQUIPMENT MFR. (336)	151	12,475	83	9/23†	7.0†	342
MISCELLANEOUS ELECTRICAL PRODUCTS MFR. (3399)	79	5,065	64	9/23†	7.0†	139
SCIENTIFIC EQUIPMENT MFR. (391)	460	10,902	24	7/13	4.0	235
METAL STAMPING, ETC. (3042)	317	10,417	33	9/23	7.0	285
WIRE & WIRE PRODUCTS MFR. (3059)	147	5,187	35	13/16	16	674
HARDWARE TOOL & CUTLERY (306)	652	10,045	15	12/20†	3.9†	235
MACHINE SHOPS (308)	527	4,746	9	12/20	3.9	111
TOTALS	4,078	172,409	42	--	--	5,762

Note: "Be" refers both to beryllium metal and to beryllium-containing materials.
SC Statistics Canada industry classification; not to be confused with SIC, the internationally used standard industrial classification.
* For 1982.
† Imputed from questionnaire survey data.
¶ Statistics Canada witholds these data because of confidentiality constraints. This number was devised from our own survey results.

It is quite likely that the number of workers handling beryllium-containing materials will increase over the next few years. The addition of new automobile assembly plants in southern Ontario (Honda in Alliston, Toyota in Cambridge, GM/Suzuki in Ingersoll, Chrysler/American Motors in Brampton, and General Motor's expansion of capacity in Oshawa) will add to the number of workers in the resistance welding category. As well, there appears to be growth potential in the manufacture of moulds used in plastics fabrication because of an increased use of plastics in automobiles.

III.4 FINAL COMMENTS

The fact that the companies reporting use of beryllium-containing materials in our questionnaire survey represent well over 10 percent of Ontario's manufacturing labour force suggests that a pretty fair representation of the Ontario situation has been achieved. This fact, coupled with the excellent response to the survey (nearly 75 percent) indicate that the data in Tables III-7, III-8, and III-9 present a reasonably accurate picture of the use of beryllium-containing materials within Ontario's manufacturing sector. In addition, the 65 percent coverage of the follow-up telephone interviews and the balanced distribution of plant visits [Table III-4] provide confidence in the descriptions presented in the body of the report (Chapters 3, 4 and 5).

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IV. TELEPHONE *PRO FORMA* USED IN THE FOLLOW-UP TELEPHONE INTERVIEWS

BERYLLIUM INDUSTRIAL USE TELEPHONE PROFORMA

Note: The term 'Be' is used to signify whatever Be alloy or compound is used by the respondent.

Attempt*	Date	Result
1.		
2.		
3.		

* If contact not made after 3 attempts, a non-response will be recorded.

NOTE: Try to establish a relaxed and non-inquisitional atmosphere with the respondent as quickly as possible. Emphasize, if you think it will help, that under no circumstances will information supplied during the interview be identified with individual companies in any of our communications with the Ministry.

1. Product

		Coding
1.1	Please be more precise about the nature of the products you manufacture.	1.1
1.2	How are your finished products used?	1.2
1.3	Are there any substitutes for Be in the manufacture of the products?	1.3

2. Process

		Coding
2.1	Please explain the manufacturing process in greater detail. ____________________ ____________________ ____________________	2.1
2.2	What type of machinery is used in connection with Be? ____________________ ____________________ ____________________	2.2
2.3	Where do you obtain the Be raw material or component? ____________________ ____________________	2.3
2.4	What particular grade of Be do you use in the process? ____________________ ____________________	2.4
2.5	How are workers involved in the process? ____________________	2.5
2.6	How could the manufacturing process lead to worker exposure to Be? ____________________ ____________________ ____________________	2.6

3. Controls

			Coding
3.1	Are there any engineering controls, e.g., ventilation, to reduce worker exposure to Be? Please elaborate. ____________________ ____________________ ____________________	[] No [] Yes	3.1
3.2	Are workers required to use personal protective equipment or clothing? Please explain what type of equipment is used or worn. (If **No** go to 3.4) ____________________ ____________________ ____________________	[] No [] Yes	3.2
3.3	Do you follow any specific cleaning and maintenance procedures for protective clothing and equipment? Please explain. ____________________ ____________________ ____________________	[] No [] Yes	3.3
3.4	Do you have any work practices specifically intended to reduce the potential for exposure? Please elaborate. ____________________ ____________________ ____________________ ____________________	[] No [] Yes	3.4

4. Workers

			Coding
4.1	Do you have a training program specifically tailored for workers handling Be? Please explain.	☐ No ☐ Yes	4.1
4.2	Do you have a medical surveillance program for workers exposed to Be? Please explain.	☐ No ☐ Yes	4.2
4.3	To your recollection, have any of your workers experienced health problems related to the use of Be? (e.g., itching skin or eyes, stuffy nose, etc.) Please explain.	☐ No ☐ Yes	4.3

5. Monitoring

5.1	Have you carried out any monitoring of airborne Be concentration? (If **No** go to 6.)	☐ No ☐ Yes	5.1
5.2	How often do you monitor airborne Be Concentration?		5.2
5.3	What range of airborne concentrations of Be have you measured?		5.3
5.4	How are these levels measured? Please describe monitoring equipment.	☐ Area ☐ Personal	5.4

6. Plant Visit

If it appears to be worthwhile, try to see whether the company would be prepared to allow us to visit their operations. The request could be phrased along the following lines: "The information you have given is important to our project and we very much appreciate your time and trouble. When we come to write the report, we have to describe the processes that are used. It would be very helpful, therefore, to see them in action. May we come and visit your plant?"

YES [ ]   NO [ ]   MAYBE [ ]
give restraints: ______________________

DON'T FORGET TO THANK THE RESPONDENT FOR ALL THEIR HELP. REMIND THEM THAT THE MINISTRY WILL SEND THEM A COPY OF OUR REPORT.

INTERVIEWERS COMMENTS (if any)